Field Tests of Concrete

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(Authorized Reprint from the Copyrighted Proceedings of the American Concrete Institute, Vol. XX, 1924)

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PORTLAND CEMENT ASSOCIATION
111 West Washington Street
Chicago

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FIELD TESTS OF CONCRETE.

BY JOHN G. AHLERS* AND STANTON WALKER.**

Tests made during the summer and fall of 1923 in New York City through the co-operation of the New York Group of Contractors and the Structural Materials Research Laboratory, Lewis Institute, Chicago.

Since the organization of the American Concrete Institute, twenty years ago, the uses of concrete have developed to such an extent that from being considered merely as a substitute for stone masonry in the construction of massive work, it has become one of our most important structural materials. The annual production of 22,300,000 bbl. of cement in the United States in 1903, and of 137,000,000 bbl. in 1923 gives some idea of the enormous increase in the volume of concrete manufactured.

Researches into the properties of concrete have been under way for many years by several investigators in the United States and Europe; but only within the past few years has extensive and accurate information, applicable to the production of concrete in the field, been obtained. In the summer and fall of 1923 strength tests of concrete were made during the period of construction of five reinforced-concrete buildings in New York City. These tests were an outgrowth of an extensive series of field investigations undertaken to establish means of introducing into practice some of the improvements in the technique of concrete-making, which recent researches have indicated are desirable and to determine the practicability of securing the compressive strength desired in concrete produced under field conditions.

The first of these field investigations was planned and carried out by the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, in co-operation with the General Committee of Contractors. The General Committee of Contractors was formed in 1921 under the joint chairmanship of M. J. Whitson, of Stone & Webster, Inc., and M. M. Upson, of the Raymond Concrete Pile Co. In May, 1922, the New York Group of Contractors was appointed as a Sub-Committee of the General Committee under the chairmanship of John G. Ahlers, to carry out similar field investigations in the New York territory, independently of the General Committee.

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**Associate Engineer, Structural Materials Research Laboratory, Chicago.

Three major investigations have been carried out: two under the auspices of the Joint Committee and the General Committee, and one through the co-operation of the New York Group of Contractors and the Structural Materials Research Laboratory, as follows:

COOPERATIVE FIELD TESTS OF CONCRETE.

Investigation.	Date (1923).	Cooperating Parties	Owner of Building.	Contractor.
I	April to July	General Committee of Contractors Joint Committee Bureau of Standards Structural Materials Research Lab.	Victor Talking Machine Co., Camden, N. J.	Stone & Webster, Inc.
II	Aug. to Oct.	New York Group of Contractors Structural Materials Research Lab.	New York Telephone Co. New York Giants Ward Baking Co. R. H. Macy Co. New York Telephone Co.	Turner Const. Co. Post & McCord, Inc. White Const. Co. Barney-Ahlers Const. Corp. Foundation Co.
III	Oct. to Dec.	General Committee of Contractors Joint Committee Bureau of Standards Structural Materials Research Lab.	Central Railroad of New Jersey, Jersey City,	Henry Steers, Inc.

This report covers only the tests listed under Investigation II in the above tabulation. The data of Investigations I and III will be reported through other channels. The members of the Committee of the New York Group of Contractors are: John G. Ahlers, chairman, Barney-Ahlers Construction Corp.; W. D. Binger, Thompson & Binger; J. E. Torrey, John W. Ferguson Co.; Aubrey Weymouth, Post & McCord, Inc.; W. Vaile, Industrial Engineering Co.; F. E. Rogers, Fred T. Ley & Co.; and J. B. Wright, American Concrete Steel Co. In carrying out these tests the contractors were represented by John G. Ahlers; the Structural Materials Research Laboratory by D. A. Abrams, Professor in Charge, and Stanton Walker, Associate Engineer. The tests were supervised by Stanton Walker. George Conahey and F. J. Rice were assistant testing engineers.

The expense of the investigation was borne by the New York Contractors and the Structural Materials Research Laboratory.

Valuable assistance was rendered by Columbia University in making available complete facilities for curing and testing the 6 by 12 in. concrete cylinders.

Acknowledgments are due the following sand and gravel companies for contributions to the Contractors' fund for carrying out these tests:

Kittanning Sales Co.
Nassau Sand and Gravel Co.
Rosoff Sand and Gravel Co.
Henry Steers, Inc.

OUTLINE OF TESTS.

A tentative program of tests was prepared after a series of conferences and was approved by the New York Group of Contractors.

It provided for carrying out tests on five different jobs, on one of which the major portion of the specimens were to be made. It required that eight 6 x 12-in. concrete cylinders for compression tests at 7d., 28d., 3m., and 1 y. be made at intervals of approximately 45 minutes for at least 20 working hours of concreting on the major job, and at least 10 hours of concreting on the four auxiliary jobs.

Concrete samples were to be selected from batches made under the usual operating conditions, and in accordance with ordinary methods of preparing the mix. After a study of the conditions on the job, samples were to be taken from batches of concrete prepared in accordance with scientific methods of designing the mix, in an endeavor to improve the uniformity and quality of the resulting concrete. The same materials were to be used in both cases.

The tests were to be carried out with practically no interference with job operations. Provisions were made to obtain complete information on the quality and uniformity of cement and aggregate, workability of concrete as measured by the slump and flow tests, time of mixing of concrete, and proportions of cement, water and aggregate.

Due to special conditions, it was impossible to adhere rigidly to the above program.

DESCRIPTION OF TESTS AND JOBS.

This investigation involved the manufacture of about 650 6 x 12-in. concrete cylinders for compression tests, sieve analyses of about 190 samples of aggregate, and the numerous miscellaneous determinations necessary to furnish complete information from which an intelligent analysis of the test results could be made.

The test data are given in Tables 1 to 18 and Fig. 9 to 11. All of the tests were made on reinforced-concrete structures for which concrete of a relatively high degree of workability was required. In general, the slump was 6 to 7 inches. For four of the jobs the aggregate was siliceous sand and pebbles from Long Island; for the fifth (Job E below) the aggregate was sand and pebbles of a dolomitic nature from Marlborough-on-the-Hudson River. Portland cement was used. Most of the concrete tested was of mixtures assumed to be equivalent to the usual 1: 2: 4. All concrete was machine-mixed in batch mixers. Table 1 gives a summary of miscellaneous information concerning each job.

A brief description of each job and an outline of the tests carried out, together with references to the tables and diagrams in which the results are recorded, is given below.

JOB A.—The major portion of the tests were carried out on Job A, selected as headquarters. It is a four-story reinforced-concrete building at Rockaway Avenue and Riverdale Street, Brooklyn, built by the Turner Con-

struction Co. for the New York Telephone Co. Fig. 1 is a photograph of the building after the concreting was finished. The work required about 7000 cu. yd. of concrete. The aggregate was "Ready-mix" gravel from Port Jefferson, L. I., furnished by the Kittanning Sales Co. Tests were made from September 12 to October 16, 1923.

For the slabs and certain of the columns the average mix used was 1 volume of cement to about 6½ volumes of aggregate, measured loose in a damp condition. This is equivalent to about a 1 : 7 mix by dry weight and a 1 : 5½ mix by dry and puddled volume. For certain columns a richer mix of about 1 : 5⅓ damp and loose was used. Each batch for the 1 : 6½ mix consisted of 5 sacks of cement and about 3500 lb. of mixed aggregate. For the 1 : 5⅓ mix 6 sacks of cement and about 3500 lb. of aggregate were used.

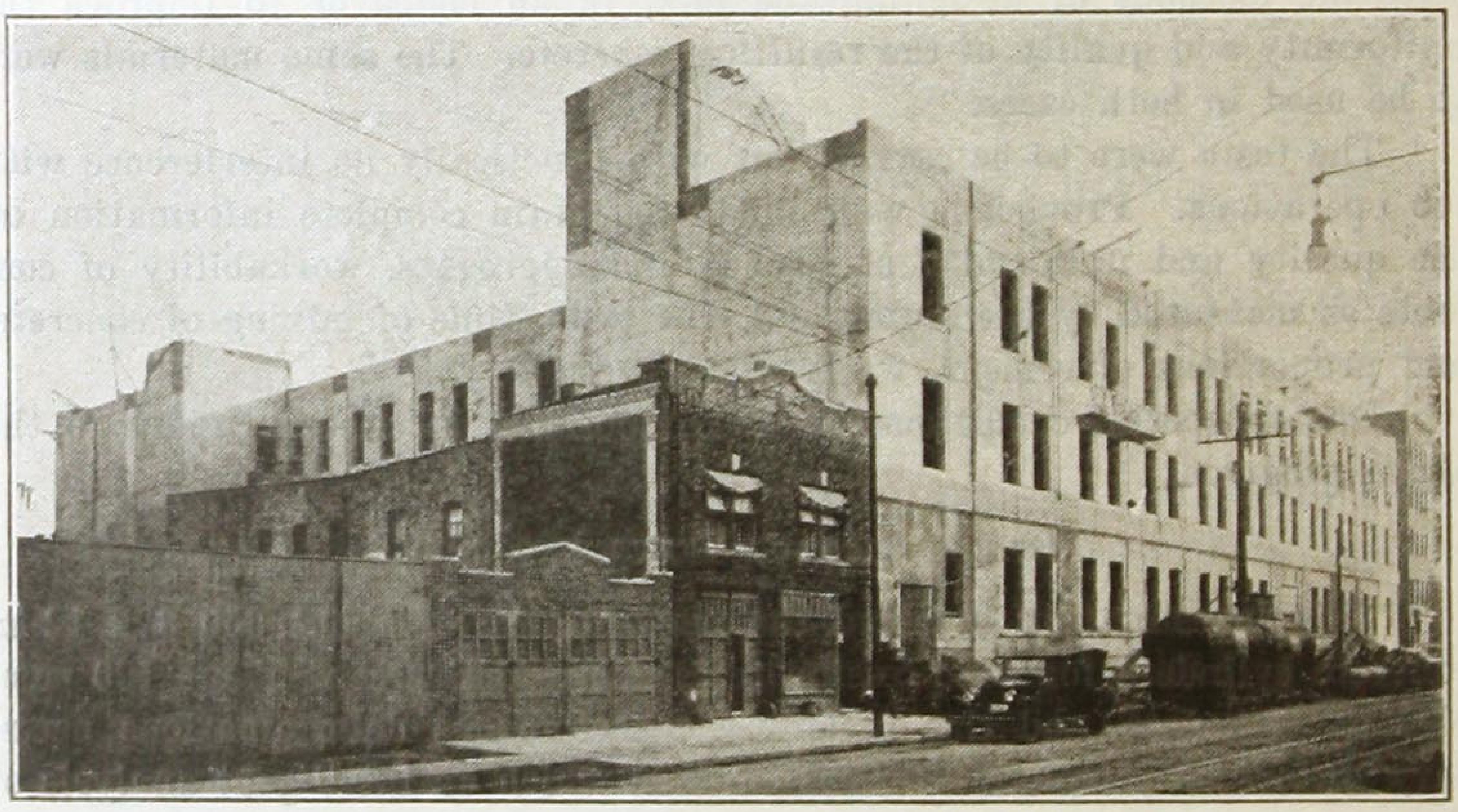

FIG. 1.—"JOB A" AFTER CONCRETING WAS FINISHED.
New York Telephone Co. Building, Rockaway Avenue and Riverdale St., Brooklyn, built by Turner Construction Co.

Forty-two batches of concrete were sampled and 291 6 x 12-in. concrete cylinders made for compression tests. For about half of the batches 8 cylinders were made from each sample for test at the four ages. For the other batches, in general, only two cylinders were made for test at 28 days. The workability of the concrete was measured for each batch by the slump and flow test. The time of mixing was determined for 16 of the test batches, and the quantity of mixing water recorded for 18 batches. Sieve analyses were made on 53 samples of aggregate selected from the stock pile and at the mixer. The results of the compression tests of the cylinders and miscellaneous data of the concrete batches are given in Table 3. The sieve analyses and miscellaneous tests of the aggregate are given in Table 9. A few tests were made to find the effect of sampling the concrete at the mixer, from the chutes, and from the slab forms. See Table 8.

Aggregate was delivered in scows to within about one mile of the job. It was unloaded by a clam-shell bucket to overhead bins from which it was loaded into trucks and hauled to the job. From the trucks it was dumped into the basement and then raised by means of a belt conveyor to a stock pile retained by vertical bulkheads. The aggregate for each batch was discharged through a gate near the bottom of the bulkhead into the metal measuring hopper on the mixer.

The concrete was mixed by a 1 cu. yd. barrel-type mixer, and hoisted and distributed by a tower and chuting system. Portland cement in sacks was handled from a storage pile to the mixer by a roller conveyor. The mixing water was measured in a 50-gal. barrel equipped with a calibrated floating gauge.

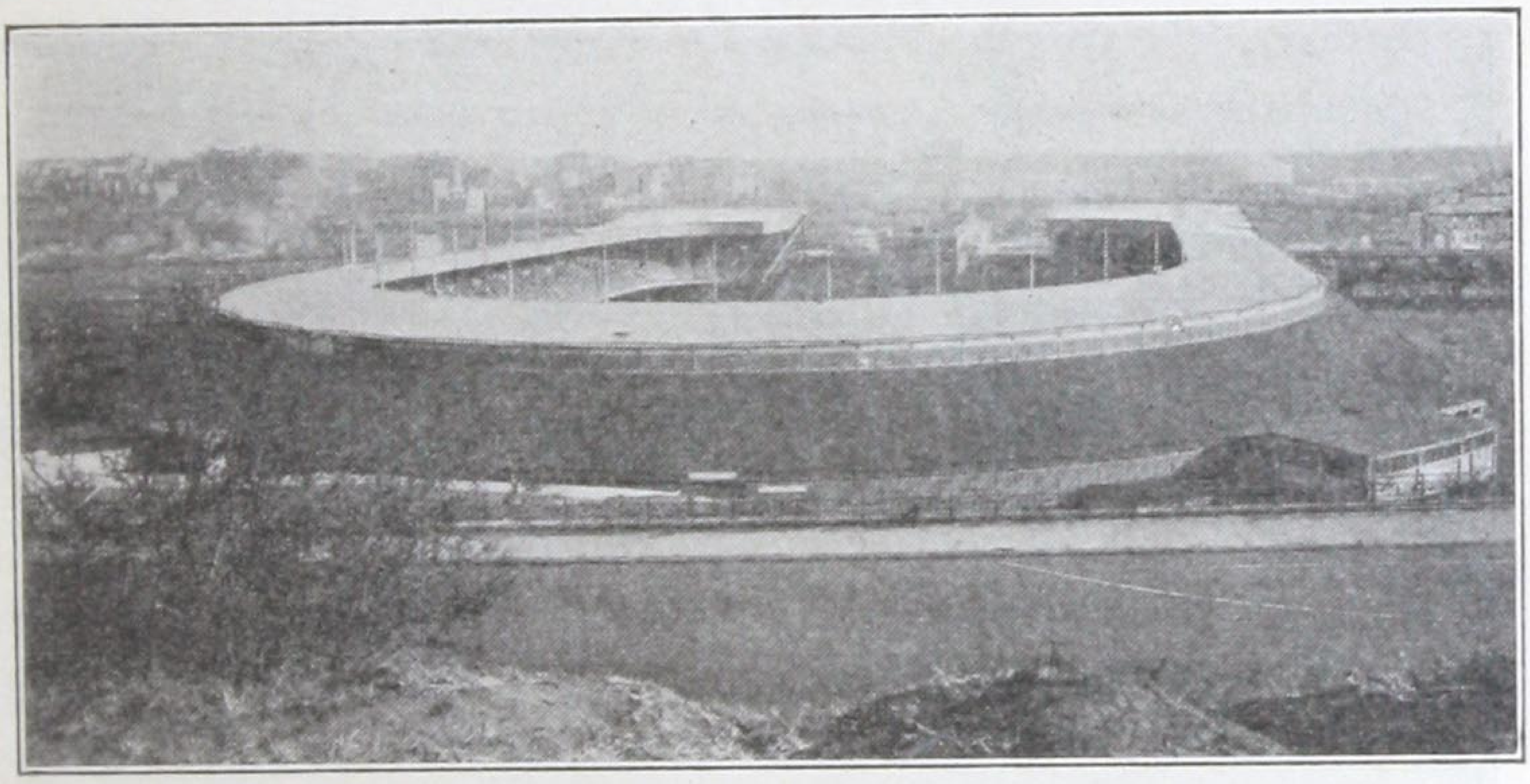

FIG. 2.—POLO GROUNDS STADIUM—JOB B.

Addition to East End, built by Post & McCord, Inc.

Although wide variations in grading of aggregate occurred, it was not practicable, because of the frequency and irregularity of these variations, to effect an economy by corrections to the grading of the "Ready-mix" aggregate. It appeared from the results of the 7-day tests that the proportions in use would, on the whole, produce the strengths required and therefore no changes were recommended.

JOB B.—Job B, under construction by Post & McCord, Inc., was at the Polo Grounds in New York City, and consisted of an addition to the stadium, which required about 7000 cu. yd. of concrete, and increased the seating capacity from about 35,000 to 55,000. Tests were started on August 6, when only about 300 cu. yd. remained to be placed, and continued until August 14. Fig. 2 is a view of the completed structure.

Sand and pebbles from the vicinity of Port Washington, L. I., furnished by the Lenox Sand and Gravel Co., were used as aggregates. The mix

specified by the architect was 1 : 1¾ : 4. Calibration of the measuring devices showed the average mix to be:

By damp and loose volume	1: 1.8: 3.8
By dry weight	1: 1.5: 4.3
By dry and puddled volume	1: 1.3: 3.7

For details of results of calibration of measuring devices see Table 12.

The maximum size of the aggregate was about ¾ in. A study of the sieve analyses showed these proportions to be economical for the conditions on this job and, therefore, no changes were recommended.

Samples of concrete were taken from 14 batches. One hundred and five 6 x 12-in. cylinders were made for compression tests at 7d., 28d., 3m., and

FIG. 3.—LAYOUT OF CONCRETE PLANT—JOB C.

Ward Baking Co. Building, 142d and Wales St., New York. One-story addition built by the White Construction Co.

ly. The workability of the concrete was measured for each batch by the slump test. The flow test was not made. Sieve analyses were made of 13 samples of sand and 13 of pebbles. The results of the compression tests of the concrete cylinders and miscellaneous data of the concrete batches are given in Table 4. The sieve analyses and moisture contents of the aggregates are given in Table 10 and the unit weights in Table 11.

The aggregates were hauled to the job in trucks, dumped on the pavement, and then transferred to the loading skip of the mixer by wheelbarrows. The concrete was mixed in a 10 cu. ft. barrel-type mixer, from which it was hoisted by means of a tower to an overhead hopper. From

the hopper the concrete was delivered to the forms by chutes or buggies, depending on the location of the work to be concreted.

The water for each batch was measured in a barrel equipped with a floating gauge. A constant quantity of water, gauged by the float, was put into each batch and then small quantities were added to obtain the proper consistency as judged by the mixer operator.

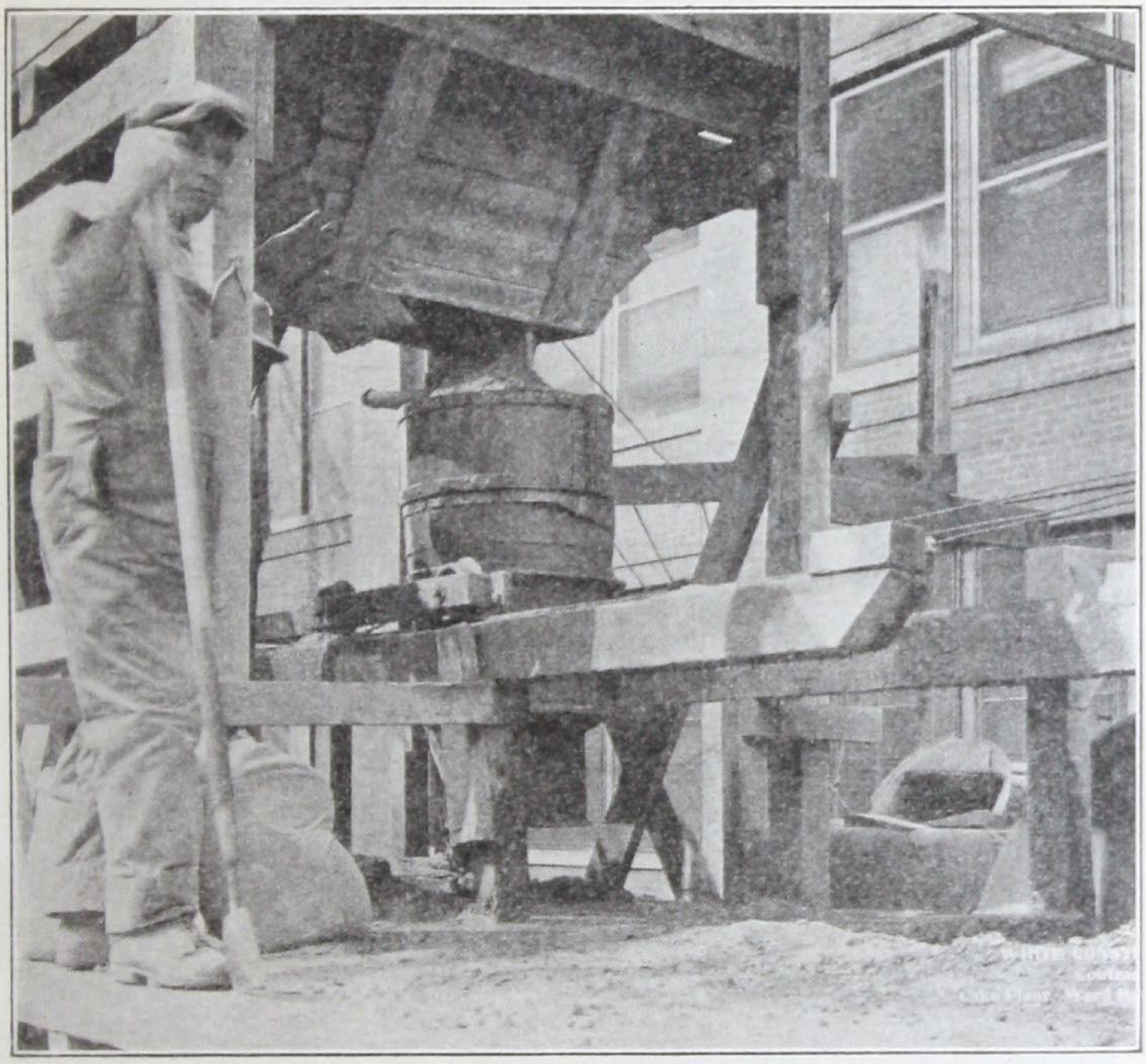

FIG. 4.—DEVICE USED ON JOB C FOR MEASURING SAND INUNDATED.

JOB C.—Job C was a one-story addition to the Ward Baking Co. building at 142d and Wales Streets, New York City, built by the White Construction Co. The aggregates were sand and pebbles from the vicinity of Port Washington, L. I., furnished by the Lenox Sand and Gravel Co. Preliminary studies of the aggregates were made before the concrete work was started, and the economical proportions to produce a slump of about 6 in. using a water-ratio of 1.0 were computed and checked by small trial batches. For the first day of concreting a mix of 1 : 2.1 : 4.4 by weight was used. Due to a change in the grading of the aggregate it was thereafter altered to 1 : 2.3 : 4.7. Tests were started on August 24 and continued

until September 7. One hundred and thirty-six 6 x 12-in. cylinders were made from 23 batches of concrete for test at 4 ages. The workability of the concrete was measured by both the slump and flow test.

The time of mixing was recorded for most of the batches. A fixed quantity of mixing water was used throughout (water-ratio 1.0). This was made possible by the special inundation measuring device for sand, described below. Sieve analyses were made of 22 samples of sand, and 21 samples of pebbles. The data of the tests are given in Tables 5, 13, and 14.

FIG. 5.—METHOD OF CHARGING MIXER WITH INUNDATED SAND—JOB C.

The aggregates were hauled in trucks and dumped on the pavement. The pebbles were transferred from the stock pile to the mixer in wheelbarrows. A bucket elevator lifted the sand to an overhead bin, from which it was discharged to the device designed by R. L. Bertin, Chief Engineer of the White Construction Co., for measuring sand under water. This apparatus consisted of a metal can of approximately 6 cu. ft. capacity divided into upper and lower compartments. The bottom of the lower compartment was adjustable so that the volume could be changed. The volume of the upper compartment could be changed by means of a collar

at the top. The operation consisted of admitting water into the can until the lower compartment was filled and sufficient water was contained in the upper compartment to completely inundate the quantity of sand required for a batch of concrete. The partition between the upper and lower compartments permitted the passage of water but not of sand. The water of inundation together with that contained in the lower compartment made up the mixing water. The can was mounted on a track in such a position that it could be moved to the mixer, tilted and its contents dumped into the mixer. Fig. 3, 4, and 5 are views of the concrete plant and of the sand measuring device. Complete description of the principles involved in

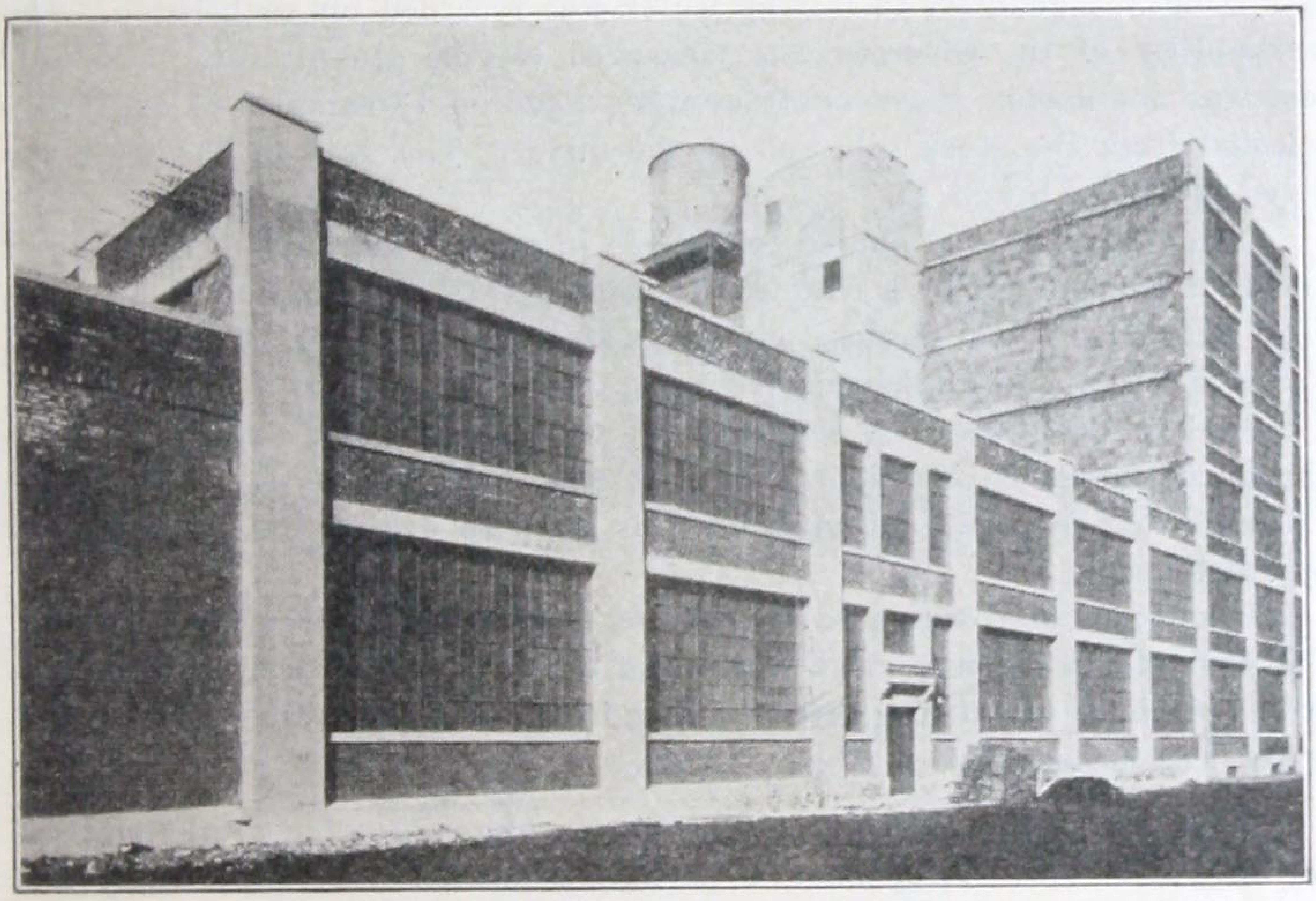

FIG. 6.—JOB D AFTER COMPLETION.

R. H. Macy Co. Warehouse, Long Island City, built by Barney-Ahlers Construction Corp.

this method of measurement of sand is given in a paper by R. L. Bertin, "Method for Measuring Sand in Inundated Condition," p. 404, 1922, Proceedings of the American Society for Testing Materials, and in "Inundation Methods for Measurement of Sand in Making Concrete," by G. A. Smith and W. A. Slater, in the 1923 Proceedings of the American Concrete Institute, page 222. The concrete was mixed in a ½ cu. yd. barrel-type mixer, and discharged directly into buggies which were carried to the work four stories above by means of an outside elevator.

JOB D.—Job D was a warehouse built at Long Island City for R. H. Macy & Co. by the Barney-Ahlers Construction Corp. Fig. 6 is a view of the building after completion. The aggregate was "Ready-mix" gravel from the same source as that used on Job A.

The average mix for most of the structural concrete (except for certain of the columns and the finish course of floor slabs) was approximately 1 : 6 damp and loose. Although wide variations in grading occurred, it was not practicable, because of the frequency and irregularity of these variations, to effect an economy by corrections to the grading of the "Ready-mix" aggregate. It appeared that the proportions in use would, on the whole, produce approximately the strengths required and, therefore, no changes were recommended.

Two batches of concrete were sampled on each of 4 different days, from September 28 to October 4. Eight cylinders were made from each sample for test at ages of 7 days, 28 days, 3 months, and 1 year. The time of mixing and quantity of mixing water was recorded for each batch. The workability of the concrete was measured by the slump test. The flow test was not made. Sieve analyses were made on 13 samples of aggregate selected from the stock pile and at the mixer. The data of the tests are given in Tables 6 and 15.

The aggregate was hauled to the job in trucks, dumped on the ground and then transferred by a clam-shell bucket to a stock pile and to an overhead bin. Fig. 7 is a photograph of the stock pile and bin. The aggregate for each batch was discharged from the overhead bin into a metal hopper attached to the mixer. A separate bin was provided for sand for use in the finish course on the floor slabs. It was available for addition to the "Ready-mix," but was not used for this purpose during the time covered by these tests.

The mixer used was a barrel-type of approximately 1 cu. yd. capacity. The concrete was hoisted in a tower and dumped into an overhead hopper, from which it was transported in buggies to the place of deposit. The water was measured in a 50-gal. barrel.

JOB E.—A few tests were made during the concreting of foundations for the New York Telephone Co. building, located between Barclay and Vesey Streets in down-town New York. The concrete work was done by the Foundation Co. "Ready-mix" gravel from the Rosoff Sand and Gravel Co., at Marlborough-on-the-Hudson, was used as aggregate.

The concrete contained about 6.25 bags of cement per cu. yd. This is equivalent to a mix of approximately 1 : 4 by dry and puddled volume. Samples were taken from the forms during the concreting of foundations. They were taken at 11 different times at intervals of not less than 30 minutes over a period of 5 days from September 14 to September 20.

Sixty 6 x 12-in. cylinders were made. The slump was measured and 4 or 12 cylinders were made for each sample of concrete and equally divided among the 4 test ages. Eighteen samples of aggregate for sieve analyses were selected from scows immediately before they were unloaded. The results of the compression tests and of the slump tests are given in Table 7. The sieve analyses are given in Table 16.

The aggregate was transported from the gravel plant on scows to within about one mile of the job. From the scows it was loaded by a clam-

shell bucket into overhead bins and from there hauled in trucks to the job, where it was dumped into a hopper leading to a bucket elevator. The elevator carried the aggregate to overhead bins, from which it was discharged into the hopper of the mixer. The concrete was mixed in two barrel-type mixers, each of approximately one cu. yd. capacity. From the mixer it was discharged into bottom-dump buckets carried on industrial trains which were pulled by gasoline engines to the vicinity of the work to be concreted. The buckets were lifted to above the forms by a derrick and the concrete dumped. The mixing water was not measured.

Laboratory Tests of Cement.—Samples of cement were selected during the course of the tests on each job and shipped to the Structural Materials Research Laboratory for test. The results are given in Tables 17 and 18.

TEST METHODS.

The tests were made in accordance with the recommendations of the American Society for Testing Materials where they were applicable and the experience gained by the Engineer of Tests during his connection in a similar capacity with the investigation carried out during the construction of Victor Talking Machine Co. Building No. 10, at Camden, N. J. The Camden investigation had been completed only a few weeks prior to starting the tests described in this paper.

The operations involved in obtaining the necessary information for the design and control of the concrete proportions are:

Aggregate
- Sampling
- Sieve analyses
- Unit weight
- Moisture content
- Absorption
- Colorimetric test for organic impurities

Calibration of Measuring Devices for Aggregate, Water and Cement

Design of Proportions

Concrete
- Sampling
- Determination of workability of concrete by slump or flow test

Compression Specimens
- Molding
- Curing
- Testing

To secure results which are indicative of the quality of the aggregates and concrete, the tests must be carried out with careful attention to detail. The art of designing and testing concrete is one that requires considerable experience and an appreciation of the effect of variations in the proportions of the concrete on its strength and other characteristics.

A brief description of the methods employed for the New York tests is given below. These methods can be applied successfully to the general problem of field control of concrete.

Sampling Aggregates.—Great care must be exercised to secure samples of aggregate which are representative of materials to be used. This is particularly true in the case of "Ready-mix" and coarse aggregates, for these, when handled, tend to segregate. In general, samples of aggregate were selected at the mixer for each batch from which compression cylinders were made.

When the aggregates were measured in wheelbarrows, a sample weighing about 50 lb. was secured by putting an occasional shovelful into a pan as the barrows were being filled. This method was used for both the sand and pebbles on Job B, and for the pebbles on Job C.

When sand was discharged from an overhead bin into the measuring device, a sample weighing about 10 to 15 lb. was secured by holding a pan in the stream of sand. Where possible 30 to 50-lb. samples of "Ready-mix" and coarse aggregates were obtained by the same method. Frequently this was impossible due to the force of the aggregate stream. In such cases the sample was shoveled from about 6 in. below the surface of the aggregate in the measuring hopper. To obtain preliminary information before concreting was started, samples were selected from the stock pile. Each sample was made up of aggregate taken from several spots about midway between the top and bottom of the pile, and at a depth of 12 to 24 in. from the surface where segregation was least.

For Job E, the samples of aggregate were selected at the scow before it was unloaded. About three samples were taken from each scow, one near each end and one near the middle, at a depth of not less than 2 ft.

Sieve Analyses.—The sieve analyses were made on dried samples, using the sieves recommended by the American Society for Testing Materials. (See for example Table 9). The sieves were shaken by hand. The amounts retained on each sieve were determined by weight. For coarse aggregate the entire sample (about 25 to 50 lb.) was tested, and for sand, about 500 grams (approx. 1 lb.), which was selected by quartering. The fineness modulus was used as a measure of the grading of the aggregate. It is the sum of the percentages in the sieve analysis divided by 100.

Unit Weight of Aggregate.—The weight per cu. ft. was determined for two conditions:

(a) Aggregate damp and loose approximating condition in measuring hopper. The test was made by shoveling average samples of the aggregate into a 1 cu. ft. cylindrical measure in such a way as to obtain as closely as could be judged the degree of compactness in the measuring hopper.

(b) Aggregate dry and puddled in cylindrical measure in accordance with Standards of the American Society for Testing Materials (C 20-21). The determination was made by filling a cylindrical measure having height equal to diameter, in three layers, and puddling each layer 25 to 30 times with a ⅝ in. round rod pointed at the lower end.

Moisture Content in Aggregate.—The moisture content was determined by drying to constant weight the samples used for sieve analyses.

Absorption of Aggregate.—Knowledge of the quantity of water absorbed by the aggregate is necessary in computing the quantity of mixing water. This determination cannot be made accurately in the field, however, and for this series of tests the absorption was not determined, because from previous knowledge of the materials used it was known to be low. Where absorption determinations are required they should be made in a laboratory.*

Colorimetric Test.—The colorimetric test for organic impurities in sand was made by digesting a sample in a 3 per cent solution of sodium hydroxide (NaOH) for 24 hours, and observing the color of the liquid above the sand. For a more complete description of this test see "Abrams—Harder Field Test for Organic Impurities in Sands," Proc. Am. Soc. Testing Mat., 1919, Part I; also "Tentative Method of Test for Organic Impurities in Sands for Concrete," Proc. Am. Soc. Testing Mat., 1921.

Calibration of Measuring Devices.—The proportions actually in use were in general, determined by weighing the quantities of materials in average batches. In other cases, where facilities for doing this were not readily available, the quantities were determined by accurate measurements of volume. The water measuring devices were marked so that the amount of mixing water could be accurately determined.

Sampling Concrete.—In order that the concrete tests may be truly representative of the quality of concrete being placed, great care must be exercised in the selection of samples. The samples for these tests were obtained as near the point of deposit as practicable. For concrete distributed by chutes, the samples were taken by holding 3-gal. pails under the discharge end of the chute. Each sample consisted of a mixture of 5 such pails full of concrete from one batch.

Where buggies were used to distribute the concrete, the samples were obtained by means of specially designed galvanized-iron sampling boxes of about 1 cu. ft. capacity placed in the top of the buggy. The dimensions of the boxes were such that they filled simultaneously with the buggies. Each sample consisted of two such boxes of concrete from one batch. Fig. 8 is a photograph of these sampling boxes, taken on the Victor Talking Machine Co. job at Camden, N. J.

On Job E, where massive foundations were being erected, the samples were taken after the concrete had been deposited in the forms.

The Standard Method of the American Society for Testing Materials, for making field tests of concrete (C 31-21), requires that all samples be selected from the forms. For this work such a method was not followed because it was necessary to obtain the samples from definite batches, which is, in general, impractical if the concrete is first placed in the forms. In

*For methods of making absorption tests see Report of Committee C-9, Proceedings of American Society for Testing Materials, vol. xx, p. 301, 1920.

many cases the method of selecting samples from the forms is objectionable also, because of the difficulty of obtaining representative samples. In the case of columns and certain other reinforced members, it is difficult to obtain a sample of any kind.

Workability.—The workability of the concrete was determined by both the slump and flow tests.

The slump test was made using a truncated metal cone 4 in. in diameter at the top, 8 in. at the bottom and 12 in. high, in accordance with the Tentative Specification, D 62-20 T of the American Society for

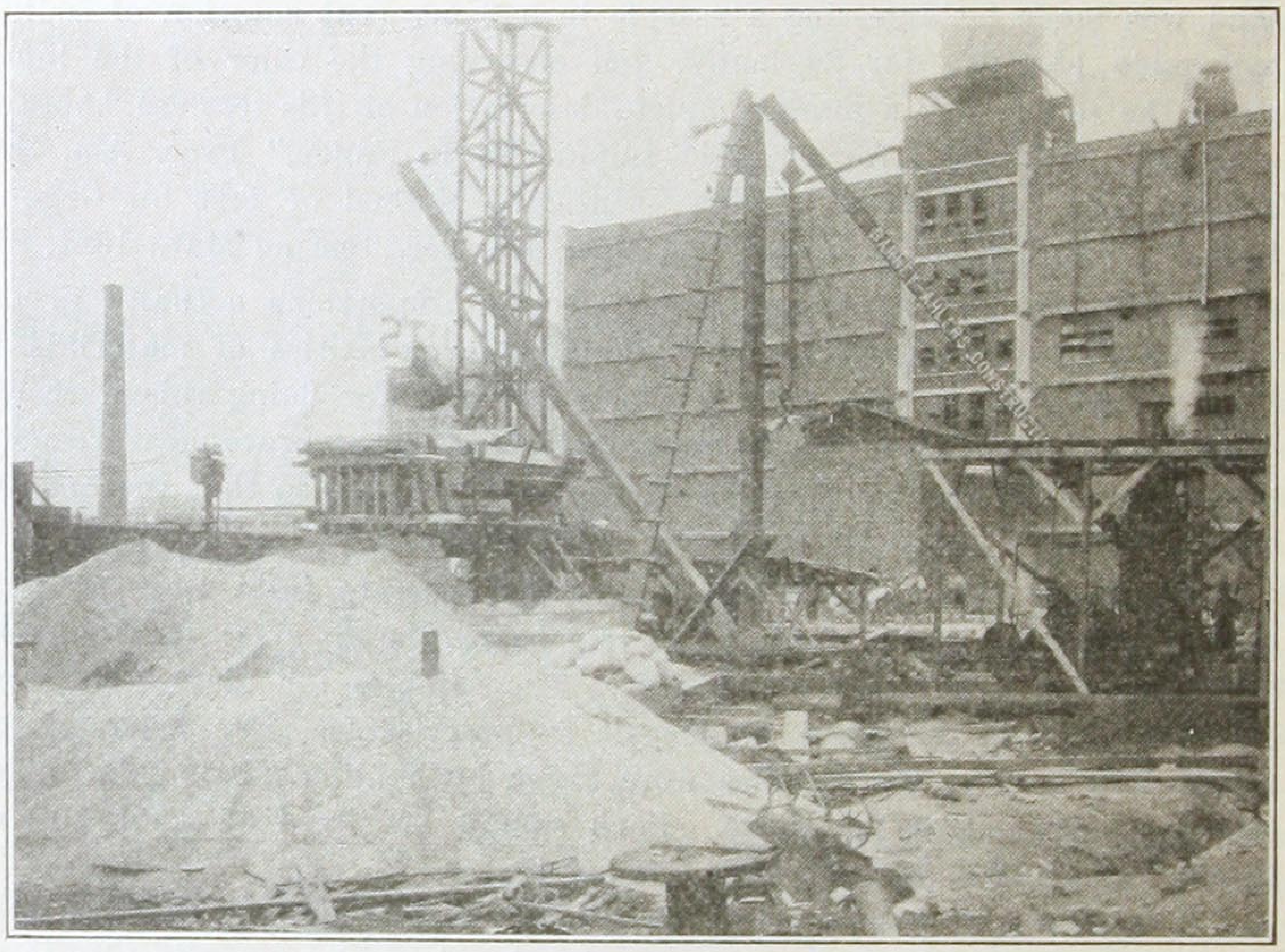

FIG. 7.—AGGREGATE STOCK PILE AND STORAGE BIN—JOB D.

Testing Materials adopted by the Joint Committee as a standard. A revision of this tentative specification, D 138-22 T provides that the slump test shall be made 3 minutes after molding the specimen. The former method was used and seems preferable. Fig. 8 is a view of the slump test being made. For convenience the flow table was used as a working platform.

The flow test was made using a flow table loaned by the U. S. Bureau of Public Roads.* The test made in accordance with recommendations of the Bureau of Standards, consists of jigging a cone of concrete on a special table (Fig. 8) and measuring the increase in bottom diameter. The con-

*For details of this flow table see "Inundation Methods for Measurement of Sand in Making Concrete," by G. A. Smith and W. A. Slater, Proc. A. C. I. vol. xix (1923), p. 227.

crete was molded in a truncated metal cone having a top diameter of 6⅔ in., a bottom diameter of 10 in., and a height of 5 in. The form was withdrawn from the concrete immediately after molding and the table raised and dropped ⅛ in. by means of a cam, 15 times in about 10 seconds. The increase in the base diameter expressed as a percentage of the original diameter, is the flow. The method employed at the Structural Materials Research Laboratory differs from the above in that a ½ in. drop is used, and the flow is taken as the final base diameter expressed as a percentage of the original diameter.

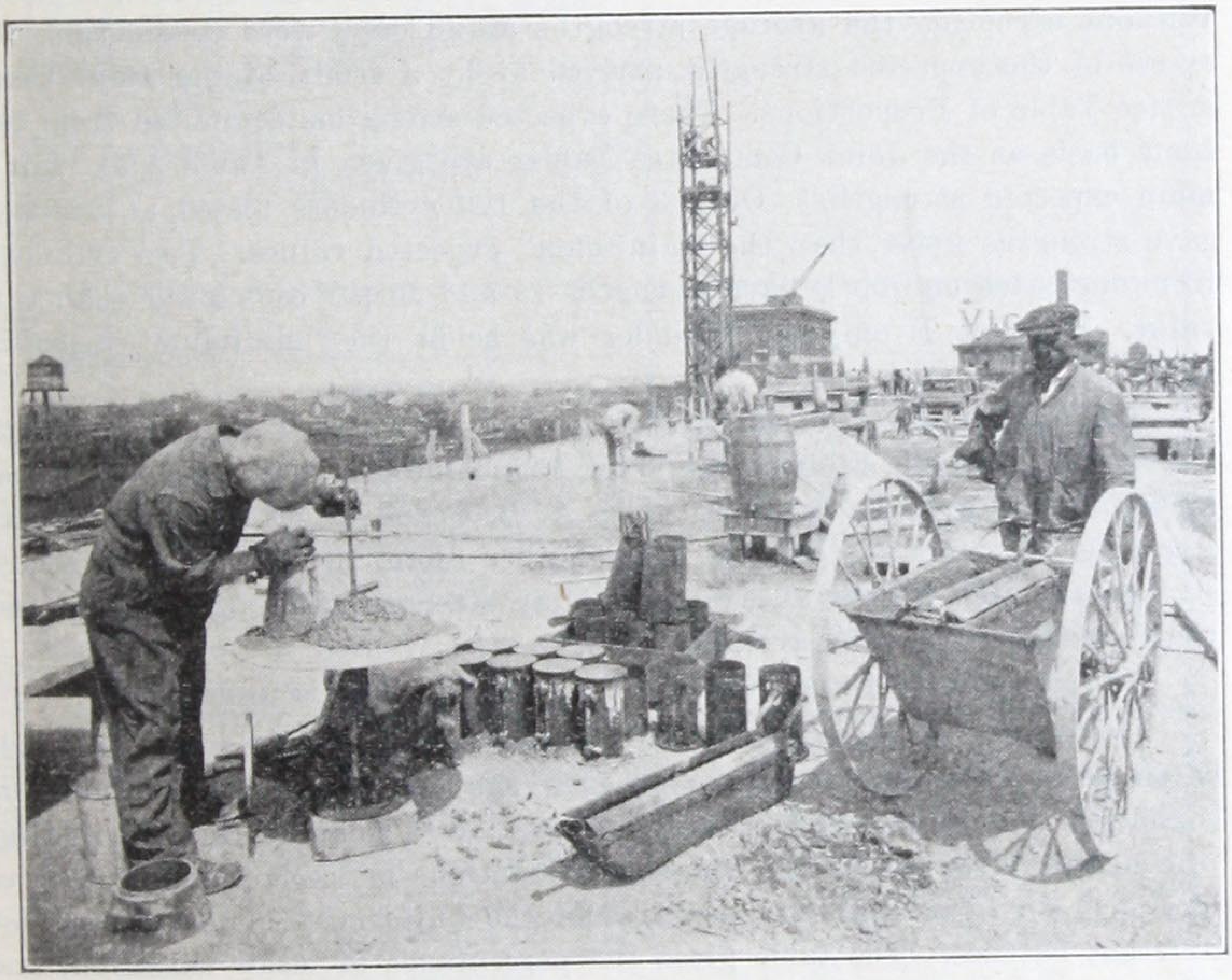

FIG. 8.—SLUMP TEST AND SAMPLING BOXES.

Molding Compression Cylinders.—The 6 x 12-in. compression cylinders were made on the work near the place where the concrete was sampled. The cylinders were molded in cylindrical metal forms set on machined cast-iron plates, in accordance with the recommendations of the American Society for Testing Materials. The specimens were removed from the forms after 16 to 20 hours and stored in damp sand until tested. The tops of the cylinders were capped with neat cement a few hours after molding, or with gypsum a few hours before testing, and a smooth surface formed by means of a machined plate.

Strength Tests.—The strength tests were made at the Testing Laboratory of Columbia University, using a 400,000 lb. Olsen or a 100,000 lb. Riehle testing machine. The cylinders were tested between steel plates. The load was applied through a spherical bearing block on top of the specimen.

DISCUSSION OF TESTS.

The data of the tests are given in Tables 1 to 18, and Fig. 9 to 11.

Strength of Concrete.—The concrete for the 5 jobs (except for certain of the columns on Job A) was of proportions assumed to be equivalent to the usual 1: 2: 4 mix. Table 2 summarizes data from Tables 3 to 7, and gives the average strengths for concrete of this mix for the 4 ages. At 28 days the average strengths ranged from 2120 for Job E to 2390 lb. per sq. in. for Job B. At 7 days the range was from 1330 to 1550 for the same jobs; and at 3 months from 2680 to 3300 for Jobs D and A respectively. Without exception the average strengths at 28 days were considerably in excess of the expected strengths arrived at by a study of the Joint Committee Table of Proportions. These expected strengths, computed from the same basis as the Joint Committee Tables are given in Table 2 as "minimum expected strength." Only 3 of the 179 cylinders tested at 28 days gave strengths lower than the "minimum" expected values. Two cylinders from one batch on Job D gave strengths 15 and 20 per cent lower than this value. For Job E only one cylinder was below the "minimum" expected value.

The "average" expected strength given in Table 1 is based on the water-ratio-strength relation for Fig. 1 in Bulletin 1 of the Structural Materials Research Laboratory. Jobs A, B, C and D gave average 28-day strengths as much as 30 per cent higher than the "average expected strengths." Job E gave an average 28-day strength about 12 per cent less than predicted from the average curve.

The strength of the concrete at 7 d. and 3 m. is discussed below:

Uniformity of Strength Tests.—The individual cylinders from a single batch gave consistent strengths at each age and, therefore, considerable confidence may be placed in the compression tests as indicating the quality of concrete in the structure. The mean variations in Table 2 and the curves in Fig. 9 give two different measures of the uniformity of the results for different batches. The table gives the percentages of mean variation, and the percentages of number of cylinders within the limits of 20 per cent of the average for the 7-d., 28-d. and 3-m. tests for each of the 5 jobs. Fig. 9 shows the cylinder strengths for each job platted in order of magnitude. The abscissas are percentages of total number of cylinders having strengths lower than the corresponding strength. The ordinates are the compressive strengths of the individual cylinders. Curves platted in this way are useful in showing clearly the maximum range in values and the number of tests falling within different limits.

The average of each of these two measures (the mean variation and the percentage of number of specimens falling within 20 per cent of the average) for the three ages at test arrange the different jobs in the same order according to uniformity of the results. The best uniformity measured by these methods was found on Jobs B and E; the mean variations were 8.5 and 8.1 per cent respectively. The greatest variations were found in the case of Jobs A and D; the mean variations were about 17.3 and 15.5

per cent. The variations for Job C were about midway between the two extremes (mean variation 11.8 per cent).

An analysis of the conditions on each of these jobs shows the causes for the differences in uniformity.

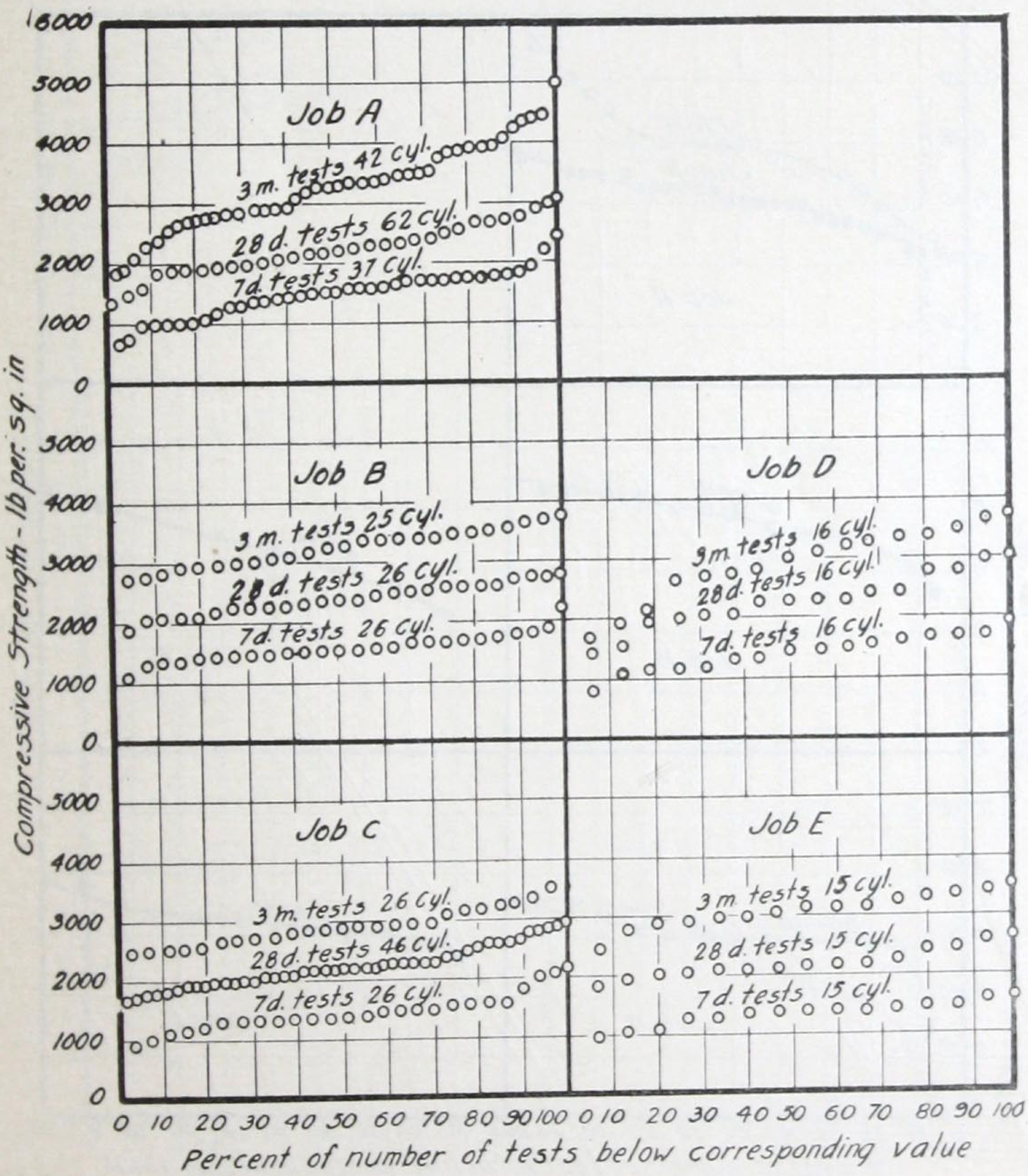

FIG. 9.—VARIATION IN STRENGTH OF CONCRETE.

Compression tests of 6 by 12-in. concrete cylinders arranged in order of magnitude.

A study of the "Ready-mix" aggregates used on Jobs A and D carried out prior to starting the tests, made it apparent that a non-uniform concrete was to be expected, due to the wide variations in grading. An inspection of the source of supply and method of preparation of this material, compared with the "Ready-mix" from other plants in the New York

District, showed that a more uniformly graded mixture could be produced than was furnished to these jobs. The authors understand that as a result of this investigation a plant which compares favorably with other "Ready-mix" plants in this territory, is being installed. Wide variations in grad-

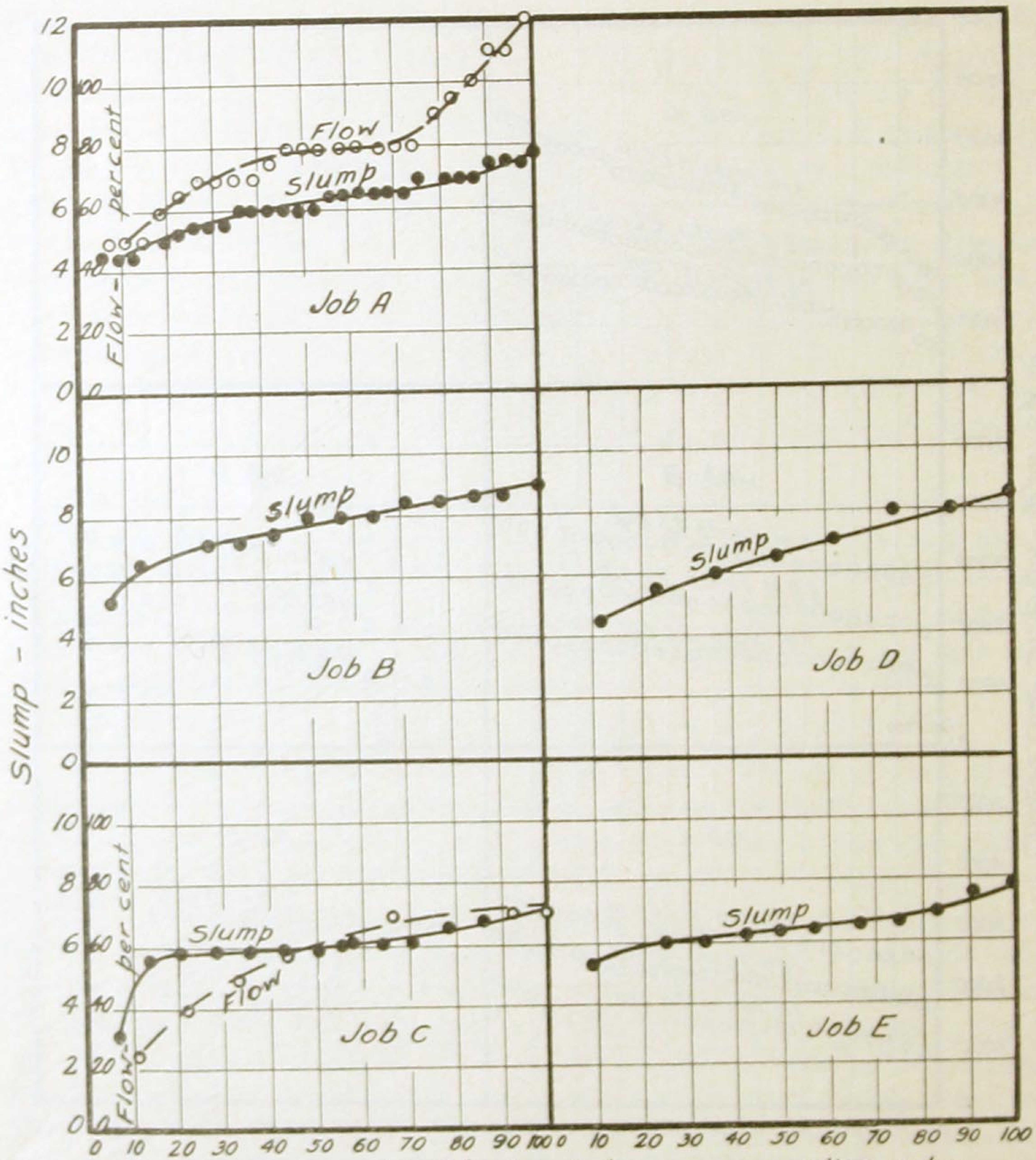

FIG. 10.—VARIATION IN SLUMP AND FLOW OF CONCRETE.
Slump and flow of concrete arranged in order of magnitude.

ing of this material were encountered for successive concrete batches on Jobs A and D. See Table 9 and Fig. 11. As a result, it was necessary to vary the quantity of mixing water to maintain a uniform workability. The method of measuring the materials permitted considerable variations in the quantities and wide variations occurred in the grading of the aggregate even from one part of the batch to another. However, the average

strengths obtained were satisfactory and in spite of the wide variations shown above only two of the 28-day cylinders for these jobs, gave strengths lower than the "minimum" value calculated on the same basis as the Tables of Proportions in the Progress Report of the Joint Committee. (See also

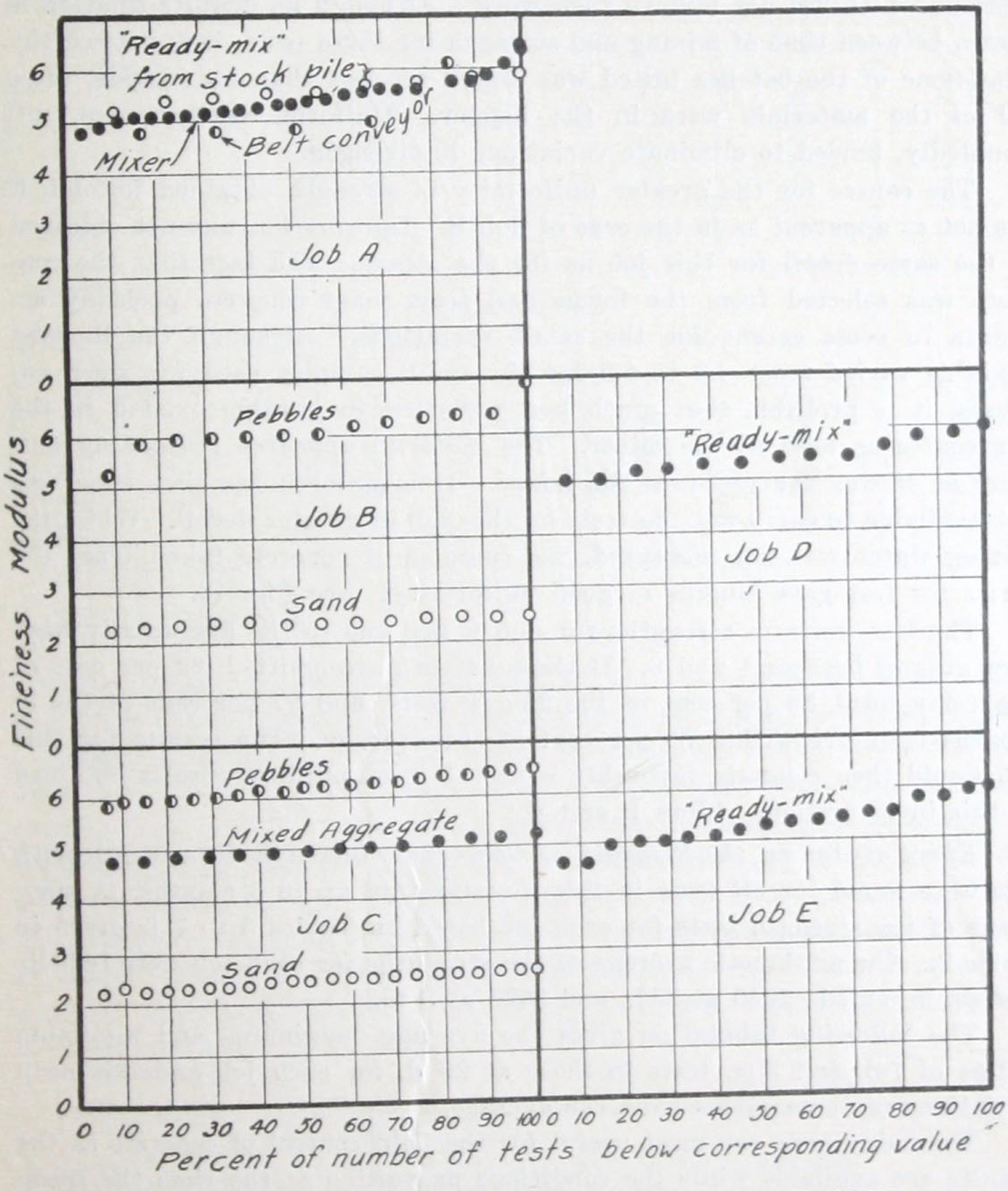

FIG. 11.—VARIATION IN FINENESS MODULUS OF AGGREGATE.

Fineness modulus of aggregate arranged in order of magnitude.

Bulletin 9 of the Structural Materials Research Laboratory.) The lack of uniformity for the strengths was due as much to the abnormally high strengths obtained as to those in the lower range.

The reasons for the uniform results on Job B seem apparent. The grading of the aggregates was fairly uniform. See Table 10 and Fig. 11. A fair degree of uniformity was maintained for the plasticity of the con-

crete. The variations in slump are not unexpected when the inherent inaccuracies of the test are considered. See Fig. 10. The aggregates were measured in carefully calibrated wheelbarrows and loaded under the direction of an architect's inspector whose sole duty was to supervise the mixing and proportioning. The concreting was done in comparatively small sections which did not involve rush work. Although no definite relation is shown between time of mixing and strength for these tests, it is noteworthy that none of the batches tested was mixed for less than 53 seconds, after all of the materials were in the hopper. Uniform weather also, undoubtedly, tended to eliminate variations in strength.

The causes for the greater uniformity in strength obtained for Job E are not as apparent as in the case of Job B. Information was not obtained in the same detail for this job as for the others. The fact that the concrete was selected from the forms and from mass concrete probably accounts to some extent for the small variations. Although the fineness modulus varied from 4.6 to 5.9 for the small samples used for sieve analyses, it is probable that much less variation in grading existed in the aggregates as used at the mixer. The material *appeared* reasonably uniform as it was charged into the mixer. It is unfortunate that time was not available to carry out the tests on this job in greater detail. While the mixing water was not measured, the samples of concrete taken from the forms for test gave slumps of good uniformity. See Fig. 10.

The less uniform strengths for Job C are due to the abnormally high strengths of batches 1 and 6. If these batches are omitted, 92 per cent of the 7-day tests, 90 per cent of the 28-day tests, and 97 per cent of the 3-months tests are within 20 per cent of the average. The results for this job would then compare favorably with the most uniform results obtained in this investigation. (Jobs B and E.)

Effect of Age on the Strength of Concrete.—Increases in strength with age were found for all tests in this investigation up to 3 months. A summary of the strength tests for each job based on Tables 3 to 7 is given in Table 2. The arithmetic average of the strengths for each job were 1420 lb. per sq. in. at 7d., 2240 at 28d., and 3020 at 3 m.

The following tabulation gives the average, maximum, and minimum ratios of 7-d. and 3-m. tests to those at 28 d. for each job and the mean variations of these ratios from the average.

The 7-day tests are most useful for the field control of concrete as the results are available while the conditions prevailing at the time the specimens were made are fresh in the minds of the persons interested. Approximately the same average ratios were obtained for each job. The mean variations and the percentages of number of values falling within 20 per cent of the average for the ratios of individual cylinders from the same batch, showed a good uniformity as compared with the strength tests at each age. It should be noted that these ratios will vary considerably with the conditions of test. Tests made at the Structural Materials Research Laboratory indicate that the ratio of 7-d. strengths to 28-d. strengths is

Job	Per Cent of Strength at 28 Days.			Per Cent of Values within 20 Per Cent of Average.	Mean Variation from Average Per Cent.
	Average.	Minimum.	Maximum.		
7-DAY TESTS.					
A*	66	36	88	81	14.1
A†	66	48	81	85	12.1
B	64	47	85	85	9.2
C	63	44	77	92	10.1
D	62	50	81	94	11.0
E	60	46	72	87	12.5
Average	64	46	81	87	11.5
3-MONTH TESTS.					
A*	137	102	169	75	12.8
A†	131	118	152	100	8.4
B	136	117	168	96	8.0
C	129	108	169	92	9.7
D	128	99	161	75	11.0
E	142	112	166	93	8.1
Average	134	109	164	88	9.7

* Mix 1-6½ damp and loose.
† Mix 1-5½ damp and loose.

generally nearer 50 per cent than the 64 per cent found for these tests. All of the specimens were cured in damp sand until test, and tested damp.

Tests made in the Joint Committee investigation on the Victor Talking Machine Co. building at Camden, N. J., indicate that at 28 days the compressive strength of field-made cylinders cured in damp sand is about the same as that of cores cut from slabs or compression specimens sawed from columns which had been cured under the same conditions as the structure. the above-mentioned tests of cores from slabs and specimens from columns as well as data from other sources* indicate that substantial increases in strength occur after 28 days. Laboratory tests show conclusively that con-

*See for example:

Effect of Age and Condition of Storage on Strength, by H. F. Gonnerman. Proc. Am. Concrete Inst., 1918.

Effect of Age on the Strength of Concrete, by D. A. Abrams. Proc. Am. Soc. Testing Mat., Part 2, 1918.

Ten-Year Tests Showing Effect of Age and Curing Conditions on the Strength of Concrete, by M. C. Withey. Eng. and Contr., vol. 54, p. 519, Nov. 24, 1920.

Effect of Age on the Strength of Concrete, by D. A. Abrams. Concrete, July, 1921.

Relation Between Molded and Core Concrete Specimens, by H. S. Mattimore. Eng. News-Record, vol. 88, No. 2, p. 73, Jan. 12, 1922.

A comprehensive bibliography of the literature of tests of concrete at different ages is available at the Structural Materials Research Laboratory.

crete increases in strength with age so long as it is not dried out and moisture is available for the progressive hydration of the cement. It is a reasonable conclusion, therefore, that tests of field specimens at later ages, say 3 months, are a better indication of the ultimate strength of the structure than tests at 28 days. This statement should not be construed as a recommendation for lowering present standards of quality of concrete.

Tests of Concrete Sampled at Different Points.—Table 8 gives results of tests of concrete taken from 4 different batches for which the samples were selected at 3 different stages in the concreting operations: (1) at the discharge of the mixer, (2) at the discharge of the chute, and (3) from the slab forms immediately after deposit. Although no great differences were found in the results of these tests, it is apparent that a sufficient number of batches was not sampled to give conclusive information. Practically the same strengths were shown for the samples taken at the mixer and from the forms. The average strength for concrete from the chute is somewhat higher than that from the other two points. The slump and flow were measured only for samples from the chute and form. The samples from the chute gave a lower slump and lower flow which is consistent with the higher strengths, and indicates that the differences are due to differences in the quality of the sample. No explanation is offered for these results other than that they are probably accidental. One theory that has been advanced from time to time is that the concrete receives additional mixing during its travel through the chutes which materially increases its strength. This apparently is not the reason for the higher strengths found in this case, for if this were so, a corresponding increase in strength would have been found for the concrete taken from the forms. The mean variation of the samples from the chute was 5.4 per cent as compared with about 9 per cent for the other two sets of tests.

Measurement of Quantities of Materials.—One of the most obvious reasons for the lack of uniformity in the strength of field-made concrete is the wide variation in quantities of materials which occurs from batch to batch, especially in the case of the aggregate and the water. A common means of measuring aggregate is the metal hopper with which the mixer is equipped. These hoppers are usually pyramidal in shape and have an area at the top of such dimensions that 1 or 2 in. difference in the level of the aggregate makes a material difference in the volume. In order to maintain the same workability the quantities of mixing water must be varied to correspond with variations in the volume of the aggregate. The moisture content of the aggregate also exerts an important influence on the quantity of the aggregate and of the mixing water. A number of different investigators have shown that sand bulks as much as 25 to 30 per cent for quantities of moisture commonly encountered under job conditions. The bulking affects the proportions of the concrete batch by changing the volume of the materials. The differences in moisture content changes the volume of mixing water. Great improvements can be made in the uniformity of field concrete if these factors are intelligently controlled. A method for

accomplishing this result, described above, was used on Job C and seems to offer a most promising means of solving the difficulty.

A great improvement over present common methods, which involves no radical changes, is the measurement of materials in hoppers having approximately vertical sides and placed in such a position that the aggregate can be readily struck off. The variations in moisture content on the job are usually small for short periods of time, and therefore, the element of bulking can usually be taken into account by varying the volume of damp and loose aggregate with changes in moisture content. Neither the bulking factor nor the amount of moisture in aggregate are as important in coarse aggregate as in sand.

Uniform proportions can also be obtained by measuring the aggregate in carefully calibrated wheelbarrows or buggies and striking it off.

Control of Concrete Proportions in the Field.—The principles outlined in the publications of the Structural Materials Research Laboratory, particularly Bulletin 1, were followed in determining what were the most economical proportions and in deciding whether the proportions in use on each job might be expected to give the required strengths. The principles involved in a consideration of the problems of this investigation may be briefly outlined as follows:

1. The strength of concrete is fixed by the quantity of mixing water expressed as a ratio to the volume of cement, so long as the concrete is workable.

2. The variation of other factors in proportioning concrete affect the strength only because they change the quantity of mixing water required to produce concrete of the desired workability.

3. For concrete manufactured under average conditions the equation $S = \frac{14000}{7^x}$ may be expected to represent the strength; where S = compressive strength at 28 days lb. per sq. in. and x = water-ratio; ratio of volume of water to volume of cement (an exponent).

4. The minimum strength to be expected is given by the equation $S = \frac{14000}{9^x}$ which is of the same form as that in 3 above.

5. Fineness modulus is a "yard stick" by which the concrete-making properties of aggregate, so far as grading is concerned, may be measured. The fineness modulus is the sum of the percentages in the sieve analysis divided by 100 when sieves No. 100, 50, 30, 16, 8, 4, 3/8 in., 3/4 in., and 1½ in., etc., are used. An important characteristic of these sieves is that the clear opening of each is double that of the next smaller sieve.

The fineness modulus of a mixture of fine and coarse aggregate is directly proportional to the fineness moduli of the separate materials and the proportions in which they are mixed. If it is desired to mix two aggregates in the proper proportions to produce a given fineness modulus,

the volume of fine aggregate expressed as per cent of the volume of fine and coarse measured separately, may be calculated from the equation,

$$p = 100 \frac{A - B}{A - C}.$$

Where p = ratio of volume of fine aggregate to volume of fine and coarse aggregate measured separately; A = fineness modulus of coarse aggregate; B = fineness modulus of mixed aggregate and C = fineness modulus of fine aggregate.

6. The maximum permissible values of fineness modulus, as given in Table 3, Bulletin 1, provide a proper basis for calculating the ratio of fine to coarse aggregate.

Changes in proportions were made during the course of the work on Job C only. It was pointed out above that for Job B the most economical ratio of fine to coarse aggregate for the materials available were in use when the tests were started. The grading of the aggregate furnished throughout the course of the tests was uniform. On Jobs A, D and E "Ready-mix" materials were used, and it was not practicable to make corrections in the grading. Changes on Job C were made because of a marked difference in the grading of the coarse aggregate furnished after the concreting was started.

To maintain a uniform quality of concrete, it is necessary to use aggregate of uniform grading, or to make proper changes in the proportions with changes in grading. This investigation showed conclusively that it is not practicable to compensate for accidental variations in grading of aggregate from batch to batch. However, when the aggregate varies in grading for different scow loads or other relatively large lots, and each lot is uniform within itself, it is practical to vary the proportions in accordance with changes in grading. This necessitates constant inspection on the job by an engineer capable of estimating such changes, and it is felt that it will be found more economical to require that the aggregates be furnished uniformly graded throughout the course of the work, and to make the inspection at the source of supply. The specifications for grading should be drawn to conform to the most economical proportions for the materials available. It is neither necessary nor desirable to apply the same specification for grading in all cases, as concrete of the same quality can be made from materials of a wide range in grading, as well as other characteristics.

Aggregate Sources in the New York District.—Inspections were made of four aggregate plants which furnish a large proportion of materials used in the New York District. In general, these plants wash the bank-run aggregates and divide them into four to seven different sizes which are recombined in the required proportions. Usually the aggregate is separated into the different sizes by washing through screens then loaded into bins, from which it is discharged to belt conveyors and transported to the scow. The proportion of different sizes is controlled by the width of open-

ing of the gate from the bin. The mixing is accomplished by discharging the materials from the various bins to the continuous belt from which in turn it is discharged to another belt and then to a hopper above a flexible loading spout which deposits the material on the scow in thin layers.

CONCLUSIONS.

In applying the results of this investigation to the general problem of field control of concrete, the conditions under which it was carried out should be kept in mind. The tests were made on work under construction by high-grade contractors, in a district where aggregates of excellent physical qualities are used. Trained organizations of long experience and adequate equipment for proportioning and mixing the concrete as measured by present standards, were used.

The following conclusions may be stated:

1. On these five jobs, where trained organizations of long experience were used, the proportions and methods employed, based on experience only, gave concrete having an average strength from 6 to 18 per cent greater than that assumed for purposes of design. It is noteworthy in this connection that many of the objectionable practices which account for unsatisfactory concrete, were not encountered on these tests.

2. With the concreting methods used on these jobs, it would be fair to expect a uniformity of strength such that not less than 75 per cent of the test specimens would fall within 20 per cent of the average strength, and not more than 5 per cent would fall below a minimum value, computed on the basis of the Joint Committee Tables of Proportions, (also published in Bulletin 9, of the Structural Materials Research Laboratory).

3. A study of the proportions and the materials, carried out in the light of knowledge now available, should enable the engineer to estimate within 20 per cent the average strength of the concrete when made in accordance with the general practices followed on these jobs.

4. Estimates of the concrete strengths made for the 5 jobs on which tests were carried out when compared with the strengths obtained, show that the water-ratio offers a practical basis for estimating the strength of concrete, if aggregates of suitable physical structure are used.

5. The fineness modulus was an accurate "yard-stick" for measuring the grading of aggregate for the purpose of determining the economical proportions of fine to coarse.

6. The maximum permissible values of fineness modulus given in Table 3, Bulletin 1, of the Structural Materials Research Laboratory may be satisfactorily applied to building construction. These values of fineness modulus produce concrete which works somewhat more harshly than that to which the mechanics are accustomed, and in certain cases a campaign of education may be desirable before the maximum values given by Table 3 are used. Reduction of these maximum values by 0.25 produces concrete which is easily worked into the forms in building construction.

7. Concrete designed under the conditions encountered in this investigation gave strengths well above the values computed on the same basis as the Joint Committee Tables of Proportions.

8. The variations in strength shown by the individual specimens for different batches were in general, the result of accidental variations in the proportions; the satisfactory agreement of different specimens from the same batch indicate that the variations were not due to the test methods employed.

9. A device which will insure a uniform quantity of aggregate from batch to batch will be of material assistance in securing concrete of uniform strength. Hoppers having vertical sides and provided with a mechanical strike-off are practicable and offer great advantages over present methods. Uniformity in the volume of sand can be maintained by the inundation method of measurement.

10. In order to secure concrete of uniform quality with the least cost for proper control, uniformly graded aggregate should be furnished throughout the course of the work. The specifications for grading should be drawn to conform to the most economical proportions for the aggregate available. It is neither necessary nor desirable to apply the same specification for grading in all cases, as concrete of the same quality can be made from aggregates of a wide range in grading and other characteristics.

11. It was not practicable to adjust the proportions on the job to compensate for variations in the grading of the aggregate which occurred from batch to batch. However, it was feasible to modify the proportions to compensate for variations in grading occurring in different scow loads or other lots of considerable size, where each lot was uniform within itself.

12. For large concrete jobs preliminary studies should be made of the aggregate at the source of supply for the purpose of determining economical proportions.

13. Scientific control can best be accomplished by using a testing organization outside that of the owner or contractor. Provision in the contract for an equitable division of the expense of scientific control, will greatly facilitate such control.

14. The experience obtained during this investigation shows conclusively the vital importance of making tests on the job to determine the strength of the concrete used. This is evident from a consideration of the definite economies which may be effected in proportioning the concrete and in designing the structure to take advantage of the known strength of the structural material employed. Definite strengths can be obtained only by: (1) rigid inspection and (2) tests of the concrete.

TABLE 1.—MISCELLANEOUS INFORMATION ON JOBS.

Field tests carried out on five different jobs in New York in 1923.
Machine-mixed portland cement concrete having slump of about 6 to 7 in. used on all jobs.
Aggregate from Long Island, except that for Job E, which was from Marlborough-on-the-Hudson.

Job.	Owner.	Contractor.	Kind of Aggregate.	Mix by Volume* (Dry and Puddled).	Period of Tests (1923).	Number of 6 x 12-in Cylinders.	Data in Tables.
A	New York Telephone Co.	Turner Const. Co.	"Ready-Mix"	1:5½	Sept. 12 to Oct. 16	291	2, 3, 8, 9
B	New York Giants (Polo Grounds)	Post & McCord, Inc.	Sand and Pebbles	1:1.8:3.8	Aug. 6 to Aug. 14	105	2, 4, 10, 11, 12
C	Ward Baking Co.	White Const. Co.	Sand and Pebbles	1:1.9:4.0 1:2.1:4.2	Aug. 24 to Sept. 7	136	2, 5, 13, 14
D	R. H. Macy Co.	Barney-Ahlers Const. Corp.	"Ready-Mix"	1:5	Sept. 27 to Oct. 4	64	2, 6, 15
E	New York Telephone Co.	Foundation Co.	"Ready-Mix"	1:4	Sept. 14 to Sept. 28	60	2, 7, 16

* Cement assumed to weigh 94 lb. per cu. ft.

TABLE 2.—SUMMARY OF CONCRETE TESTS.

Compression tests of 6 x 12-in. concrete cylinders made in field.
Mixtures approximately equivalent to 1:2:4; the richer mixtures tested for Job A omitted from average.
Machine-mixed portland cement concrete.
Aggregate from Long Island, except that for Job E, which was from Marlborough-on the-Hudson.
Values for expected strengths based on water-ratio-strength relation. The "minimum" expected strength calculated from equation, $S=\frac{14000}{9^x}$; the "average" expected strength from equation $S=\frac{14000}{7^x}$; where S=compressive strength at 28 days in lb. per sq. in., and x=water-ratio (an exponent). The first equation was used as the basis of the Joint Committee Tables of proportions (also published in Bulletin 9 of the Structural Materials Research Laboratory; the second equation is from Bulletin 1 of the Structural Materials Research Laboratory).
The "mean variations" are the averages of the variations of the individual strengths from the average strength of all cylinders for a given job tested at a given age, expressed as a percentage of the average strength.

Job.	Workability.		Water-Ratio.	Compressive Strength, lb. per sq. in.				Expected Compressive Strength at 28 days, lb. per sq. in.	
	Slump.	Flow, per cent.		7 day.	28 day.	3 mo.	Average.	Minimum.	Average.
A	6.1	80	1.1	1450 (37)[a] (62)[b] 19.7[c]	2130 (76)[a] (72)[b] 14.4[c]	3040 (34)[a] (85)[b] 17.8[c]	.... 73[b] 17.3[c]	1250	1650
B	7.7	..	1.0	1550 (26)[a] (92)[b] 10.9[c]	2390 (26)[a] (100)[b] 8.2[c]	3230 (26)[a] (100)[b] 7.4[c]	.... 97[b] 8.5[c]	1550	2000
C	5.9	60	1.0	1430 (26)[a] (70)[b] 14.7[c]	2180 (46)[a] (83)[b] 11.7[c]	2890 (26)[a] (93)[b] 9.1[c]	.... 82 11.8	1550	2000
D	6.8	..	0.95	1380 (16)[a] (75)[b] 17.4[c]	2260 (16)[a] (62)[b] 14.7[c]	2880 (16)[a] (62)[b] 14.3[c]	.... 66[b] 15.5[c]	1700	2200
E	6.4	..	0.9	1300 (15)[a] (80)[b] 10.2[c]	2120 (15)[a] (94)[b] 7.5[c]	3040 (15)[a] (100)[b] 6.8[c]	.... 91[b] 8.1[c]	1900	2400
Average[d].	6.6	70	0.99	1420 (76)[b] 14.4[c]	2220 (82)[b] 11.3[c]	3020 (88)[b] 11.1[c]	.... 82[b] 12.2[c]	1600	2050

[a] Number of specimens tested.
[b] Per cent of total number of specimens falling within 20 per cent of the average.
[c] Mean variation, per cent.
[d] Averages not weighted for number of specimens.

TABLE 3.—COMPRESSION TESTS OF CONCRETE—JOB A.

Compression tests of 6 x 12-in. concrete cylinders made in field.
Aggregate: "Ready-mix" gravel from Port Jefferson, Long Island, furnished by Kittanning Sales Co.
Portland cement was used.
Mix for 5 bag batches by damp and loose volume 1:6½; by weight 1:7; by dry and puddled volume 1:5⅙.
Same quantity of aggregate used for 6 bag batches.
Samples selected from about 1 cu. yd. batch during discharge from chute.
Specimens cured in damp sand until test; tested damp.

Batch.	Date Sampled (1923).	Time of Mixing, sec.: Loading.	Time of Mixing, sec.: Mixing.	Time of Mixing, sec.: Discharging.	Mixing Water, gallons per batch.	Slump in.	Flow, per cent.	Compressive Strength, lb. per sq. in.: 7 day.	Compressive Strength, lb. per sq. in.: 28 day.	Compressive Strength, lb. per sq. in.: 3 mo.	Batch.	Date Sampled (1923).	Slump in.	Flow, per cent.	Compressive Strength, lb. per sq. in.: 28 days.
CEMENT PER BATCH—5 BAGS.															
3	9-12	..	..	..	....	6.5	45	1020 990 1017	1650 1860 1780	....	20	9-25	6.5	80	2210 2070 2140
4	9-12	..	..	..	..	6.0	..	1140 1140	2040 2210 2120	....	21	9-25	6.5	80	1805 1890 1840
5	9-14	..	..	..	....	7.5	110	1490 1270 1380	2350 2240 2290	3970 3240 3600	22	9-25	5.25	80	2500 2120 2310
6	9-14	..	45	..	31.9	7.5	110	1790 1710 1750	2990 3040 3020	3410 3880 3650	23	9-25	4.5	50	2260 2480 2370
7	9-14	..	45	..	31.9	6.5	95	1580 1670 1620	2690 2870 2780	4250 2940 3600	24	9-25	4.5	50	1930 2000 1960
8	9-14	..	60	..	33.0	6.0	80	1420 1560 1490	2650 2120 2380	2840 3290 2930	25	9-26	7	..	1940 1930 1940
9	9-14	..	65	..	34.6	5.5	70	1440 1390 1410	2650 2270 2460	3380 3350 3360	26	9-26	7	120	2650 2660 2660
11	9-19	25	38	35	36.0	4.5	70	1470 1530 1500	2350 1790 2070	2900 2940 2920	27	9-26	6	80	2300 2310 2300
12	9-19	30	30	40	34.2	7.0	90	2180 2310 2310	2730 2900 2820	2780 4340 3560	28	9-29	4.5	55	1910 1810 1860
13	9-19	40	20	35	33.6	6.0	80	1680 1730 1700	2140 2540 2340	3360 2780 3070	29	10-2	5.0	60	1880 2090 1980
15	9-20	..	..	..	....	5.0	75	1570 1710 1640	2190 2370 2280	3150 3500 3320	30	10-2	4.0	50	1840 1930 1880
16	9-20	30	30	35	35.3	5.5	70	1810 1950 1880	2720 2510 2620	3330 3940 3640	31	10-2	6.0	70	1740 1610 1680

TABLE 3.—*Continued.*

Batch.	Date Sampled (1923).	Time of Mixing, sec.			Mixing Water, gallons per batch.	Slump in.	Flow, per cent.	Compressive Strength, lb per sq. in.			Batch.	Date Sampled (1923).	Slump in.	Flow, per cent.	Compressive Strength, lb. per sq. in.
		Loading.	Mixing.	Discharging.				7 day.	28 day.	3 mo.					28 days.
CEMENT PER BATCH—5 BAGS.															
17	9-20	30	30	30	31.2	6.0	70	1480 1350 1420	2180 2480 2330	2700 2520 2610	32	10-8	7.5	1 25	1900 2040 1970
18	9-20	30	20	40	30.4	6.5	80	1610 1710 1660	2360 2120 2240	2900 3220 3060	33	10-8	4	65	1680 1580 1650
19	9-20	..	..	..	....	6.5	80	1670 1650 1660	1900 2140 2020	3060 2850 3460	34	10-10	5.5	60	1570 1880 1725
37	10-15	26	23	40	34.5	...	..	1320 1270 1300	2000 1850 1920	2640 2350 2500	35	10-10	4.5	50	2370 2670 2520
38	10-15	21	39	44	34.5	7	..	975 975 975	1600 1340 1470	1900 1850 1880	36	10-10	6	100	1860 1840 1850
39	10-16	30	25	30	34.5	7	..	665 720 690	1380 1980 1530	2290 2120 2200	41	....	...	..	2070 2000 2040
40	10-16	30	25	30	34.5	7.75	..	1030 980 1000	1785 1650 1720	2810 2610 2710	42	....	...	..	2060 2010 2035
Grand average.........					33.7	6.1	80	1450	2130	3040					
Mean variation, per cent					....	...	..	19.7	14.4	17 8					
CEMENT PER BATCH—6 BAGS.															
1	9-12	..	..	..	....	4.2	55	1810 2880 2340	3760 4050 3950	4450 5000 4725					
2	9-12	..	..	..	....	7.0	50	2300 2050 2180	3210 3440 3320	4500 4050 4275					
10	9-19	30	30	40	36.0	3.5	50	1910 1750 1830	2680 2950 2820	3440 3620 3530					
14	9-19	25	25	35	35.3	6.0	80	1670 2060 1860	2570 2540 2560	3740 3850 3790					
Grand average..........					35.6	5.2	58	2050	3160	4080					
Mean variation, per cent.					....	...		12.6	14.7	10.4					

TABLE 4.—COMPRESSION TESTS OF CONCRETE—JOB B.

Compression tests of 6 x 12-in. concrete cylinders made in field.
Aggregate: Sand and pebbles from Port Washington, Long Island, furnished by Lenox Sand and Gravel Co.
Portland cement was used.
Mix by volume damp and loose 1:1.8:3.9; by dry weight 1:1.5:4.3; by volume dry and puddled 1:1.3:3.7.
Samples selected from two-sack batch of concrete, near place of deposit.
Specimens cured in damp sand until test; tested damp.

Batch.	Date Sampled (1923).	Time of Mixing, sec.			Slump, in.	Compressive Strength, lb. per sq. in.		
		Loading.	Mixing.	Discharging.		7 day.	28 day.	3 mo.
1	8-6	10	65	15	8.5	1420	2800	3460
						1490	2580	3430
						1450	2590	3450
2	8-7	10	75	10	8.5	1510*	2260	2850
						1420*	2090	2780
						1460	2180	2820
3	8-7	..	..	..	8.7	1510*	2300	3080
						1530*	2250	2940
						1520	2280	3010
4	8-8	10	90	15	9.0	1500*	2140	3270
						1510*	2260	3000
						1500	2200	3135
5	8-8	..	..	..	8.7	1640*	1920	3000
						1630*	2060	2930
						1640	1990	2975
6	8-9	20	85	15	6.5	1770*	2620	3380
						1830*	2700	3380
						1800	2660	3380
7	8-9	20	55	20	7.2	1440*	2360	3540
						1350*	2380	3060
						1390	2370	3300
8	8-9	17	53	15	8.0	1710*	2510	....
						1800*	2590	3440
						1760	2550	3440
9	8-9	10	70	10	7.2	1450*	2110	3540
						1290*	2040	2860
						1370	2080	3200
10	8-14	12	80	20	8.0	1410	2360	3135
						1080	2300	2940
						1250	2330	3030
11	8-14	10	80	10	6.5	1560	2500	3380
						1650	2740	3360
						1600	2620	3370
13	8-14	17	110	15	8.0	1350	2420	3695
						2190	2480	3760
						1770	2450	3720
14	8-14	10	65	10	5.3	1630	2710	3380
						1680	2720	3230
						1660	2720	3300
Grand average					7.7	1550	2390	3230
Mean variation, per cent					...	10.0	8.2	7.4

* Age at test, 9 to 11 days.

TABLE 5.—COMPRESSION TESTS OF CONCRETE—JOB C.

Compression tests of 6 x 12-in. concrete cylinders made in field.
Aggregate: sand and pebbles from Port Washington, Long Island, furnished by Lenox Sand and Gravel Co.
Portland cement was used.
Samples selected from buggies by means of sampling box, during discharge of about ½ cu. yd. batch from mixer.
Specimens cured in damp sand until test; tested damp.

Batch.	Date Sampled (1923).	Time of Mixing, sec.	Slump, in.	Flow, per cent.	Compressive Strength, lb. per sq in.			Batch.	Date Sampled (1923).	Slump, in.	Flow, per cent.	Compressive Strength, lb. per sq. in.
					7 day.	28 day.	3 mo.					28 days.
MIX BY VOLUME, DRY AND PUDDLED 1:1.9:4.0												
1	8-24	145	6 0	..	2110 2010 2060	2750 2800 2780	3170 3250 3210	..	...	..	..	....
2	8-24	80	5.75	..	1300 990 1140	2000 2240 2120	2610 2480 2540	..	...	..	..	....
3	8-24	..	6.0	..	1330 1350 1340	2350 2250 2300	2880 3110 2990	..	..	..	..	....
4	8-24	68	6.75	..	1380 1370 1370	.470 2250 2360	2780 2800 2790	..	...	..	..	....
MIX BY VOLUME, DRY AND PUDDLED 1:2.1:4.2												
5	8-28	96	6.5	60	1420 1450 1440	2580 2360 2470	2820 2840 2830	14	9-5	..	..	2240 2210 2220
6	8-28	75	7.0	70	2000 1800 1900	2760 2870 2820	3370 3590 3480	15	9-5	..	..	1640 1790 1720
7	8-28	39	6.0	70	1540 1510 1520	2170 2040 2100	3080 2520 2800	16	9-5	7.0	..	1900 2140 1970
8	8-28	87	3.0	25	1590 1480 1540	2160 2460 2310	2460 2660 2560	17	9-5	..	..	1970 1960 1960
9	8-28	38	8.75	50	1360 1360 1350	2115 2260 2190	2830 2870 2850	18	9-5	..	..	1960 1890 1920
10	8-31	92	5.75	70	1560 1460 1510	2580 2840 2710	3620 3270 3440	19	9-7	..	..	2160 2140 2150
11	8-31	73	5.75	40	1330 1310 1320	2150 1770 1960	2500 2660 2580	20	9-7	..	..	2160 2270 2220
12	8-31	87	5.5	70	1190 1120 1160	1890 1900 1900	2860 2500 2680	21	9-7	..	..	2580 2780 2680
13	8-31	133	5.75	60	900 1070 980	1700 1760 1730	2660 2980 2820	22	9-7	..	..	2060 2090 2080
								23	9-7	..	..	2070 1810 1940
Grand average............			5.9	60	1430	2180	2890					
Mean variation, per cent..			....	....	14.7	11.7	9.1					

TABLE 6.—COMPRESSION TESTS OF CONCRETE—JOB D.

Compression tests of 6 x 12-in. concrete cylinders made in field.

Aggregate: "Ready-mix" gravel from Port Jefferson, Long Island, furnished by Kittanning Sales Co.

Portland cement was used.

Mix by volume: damp and loose, approximately 1:6.

Concrete samples selected from buggies by means of sampling box, during discharge, of about 1 cu. yd. batch from mixer.

Cylinders cured in damp sand until test; tested damp

Batch.	Date Sampled (1923).	Time of Mixing, sec.			Cement per Batch, bags.	Mixing Water, gallons per batch.	Slump, in.	Compressive Strength, lb. per sq. in.		
		Loading.	Mixing.	Discharging.				7 day	28 day.	3 mo.
1	9-28	30	30	20	6	37.6	8	1110 1110	2220 2220	2610 2600
								1110	2220	2600
	9-28	..	..	..	6	37.6	8	780 1040	1440 1540	1620 1900
								860	1490	1760
3	10-1	20	25	30	6	28.5	8.5	1310 1400	2400 2360	3020 2740
								1360	2380	2880
4	10-1	20	35	23	6	29.8	5.5	1660 1700	2990 2760	2970 3610
								1680	2875	3290
5	10-2	40	3	28	6	29.8	6	1610 1540	1990 2070	3160 3350
								1580	2030	3255
6	10-2	20	18	10	6	32.3	6.5	1300 1140	1960 2080	2140 2690
								1220	2020	2415
7	10-4	25	45	20	6	31.6	4.5	1920 1640	3000 2760	3640 3460
								1780	2880	3550
8	10-4	28	62	20	6	31.6	7	1490 1440	2220 2240	3370 3220
								1460	2230	3295
Grand average			....	....	....	32.4	6.8	1380	2260	2880
Mean variation, per cent			....	....	....	....	...	17.4	14.7	14.3

TABLE 7.—COMPRESSION TESTS OF CONCRETE—JOB E.

Compression tests of 6 x 12-in. concrete cylinders made in field.
Aggregate: "Ready-mix" gravel from Marlborough-on-the-Hudson, furnished by Rosoff Sand and Gravel Co.
Portland cement was used.
Concrete samples selected from forms for massive foundations.
Cylinders cured in damp sand until test; tested damp.

Sample	Date Sampled (1923).	Slump, in.	Compressive Strength, lb. per sq. in. 7 day.	28 day.	3 mo.
1	9-14	...	980	2110	2850
			1060	2000	3290
			1010	2180	2440
			1020	2090	2860
2	9-17	5.5	1420	2400	3490
		5.2	1350	2660	3010
		6.4	1320	2540	3250
			1360	2530	3250
3	9-18	6.4	1550	2140	3400
4	....	7	1600	2210	3120
5	....	6	1430	2420	3320
6	9-19	6	1240	1800	2980
7	....	6.5	1320	1940	2790
8	....	6.5	1350	2050	2970
9	9-20	7.5	1300	2080	3120
10	....	6.2	1370	2010	2880
11	....	7.8	1240	2070	3090
Grand average	....	6.4	1300	2120	3060
Mean variation, per cent	....	...	10.2	.57	6.8

TABLE 8.—TESTS OF CONCRETE SAMPLED AT DIFFERENT POINTS—JOB A.

Compression tests of 6 x 12-in concrete cylinders.
Mix: about 1:5½ by volume, dry and puddled.
Aggregate: "Ready-mix" gravel from Port Jefferson, Long Island, furnished by Kittanning Sales Co.
Portland cement was used.
Three samples selected from a batch of approximately 1 cu. yd.; at mixer, discharge end of chute, and from forms.
Age at test 28 days.
Cylinders cured in damp sand until test; tested damp.

Batch.	Date Sampled (1923).	Slump, in. Mixer.	Chute.	Forms.	Flow, per cent Mixer.	Chute.	Forms.	Compressive Strength, lb. per sq. in. Mixer.	Chute.	Forms.
28	9-29	..	4.5	5.0	..	55	65	1540	1910	1450
								1520	1810	1600
								1530	1860	1520
29	10-2	..	5.0	7.0	..	60	85	1910	1880	1840
								2070	2090	1630
								1990	1980	1740
30	10-2		4.0	6.0	..	50	80	1550	1840	1850
								1760	1930	1470
								1660	1880	1660
31	10-2	..	6.0	7.0	..	70	100	1510	1740	1760
								1710	1610	1940
								1610	1720	1850
Grand average			4.9	6.2	..	58	82	1700	1860	1690
Mean variation, per cent			...	...	..	..	..	9.1	5.4	9.2

TABLE 9.—SIEVE ANALYSES AND MOISTURE CONTENT OF AGGREGATE—JOB A.

Aggregate: "Ready-mix" gravel from Port Jefferson, Long Island
Average weight of aggregate: damp and loose, 112 lb. per cu. ft.; dry and puddled, 128 lb.

Sample.	Date Sampled (1923).	Place Sampled.	Moisture, per cent by weight.	Amount Coarser than each Sieve, per cent by weight.										Fineness Modulus.*
				100	50	30	16	8	4	⅜	¾	1	1½	
1	9-9	Stock pile.........	...	99	93	80	72	63	54	43	31	26	5	5.40
2	"	" "	...	99	93	84	73	69	65	40	24	21	1	5.48
3	"	" "	...	99	96	83	73	68	63	40	26	22	0	5.48
4	"	" "	...	99	95	79	69	64	60	34	21	16	0	5.21
5	"	" "	...	99	94	84	75	67	61	46	30	24	10	5.66
6	"	" "	...	99	92	81	76	71	67	57	43	36	5	5.91
7	"	" "	2.3	99	96	86	78	74	69	42	27	21	3	5.74
10	9-12	At mixer	...	99	99	91	76	60	45	28	14	10	2	5.14
11		5 samples from one	...	99	98	90	75	62	49	32	17	11	0	5.22
12		batch collected at	...	100	99	91	79	69	57	35	17	12	3	5.50
13		different	...	100	99	96	89	85	79	61	27	16	2	6.38
14		intervals	...	99	99	91	80	71	64	50	32	21	9	5.95
15	9-12	Mixer..............	...	100	98	92	83	77	70	50	22	11	0	5.92
16	"	Mixer (Batch 5)...	...	99	95	84	73	64	56	31	10	4	0	5.12
17	"	" (" 6)...	1.7	99	95	84	74	66	61	37	14	6	0	5.30
18	"	" (" 7)...	1.6	99	93	81	74	66	59	42	23	16	1	5.38
19	"	" (" 8)...	1.7	99	93	80	72	62	53	35	19	4	0	5.13
20	"	" (" 9)...	1.6	99	97	90	80	71	65	47	28	21	2	5.79
21	"	Belt conveyor.....	...	99	98	86	69	55	42	24	10	5	0	4.83
22	"	" "	...	99	97	83	61	55	45	29	13	5	1	4.81
23	"	" "	...	100	97	82	64	50	42	27	13	9	4	4.79
24	"	" "	...	99	98	86	68	55	47	30	13	8	2	4.98
25	9-18	Stock pile.........	1.7	..	..	..	..	..	..	..	..	..	..	....
26	"	" "	1.8	..	..	..	..	..	..	..	..	..	..	....
27	9-19	Mixer (Batch 10)..	1.8	99	98	89	72	56	42	22	7	4	0	4.65
28	"	" (" 11)..	1.4	99	98	89	74	65	57	41	19	11	2	5.44
29	"	" (" 12)..	1.4	99	93	81	67	57	49	37	24	17	6	5.13
30	"	" (" 13)..	2.1	98	91	82	74	61	51	39	26	23	3	5.25
31	"	" (" 14)..	2.1	98	92	82	73	60	49	37	25	23	3	5.19
32	9-20	" (" 15)..	2.1	99	98	82	73	55	39	28	20	18	3	4.92
33	"	" (" 16)..	...	97	95	86	76	63	54	38	21	15	0	5.30
34	"	" (" 17)..	1.4	99	96	92	89	81	72	52	29	23	3	6.13
35	"	" (" 18)..	...	..	..	..	..	..	..	49	35	29	4	....
36	9-25	Belt conveyor.....	2.3	99	95	90	85	73	65	56	42	37	9	6.14
37	"	" "	1.9	99	96	91	87	78	72	64	50	42	5	6.42
38	"	Truck............	...	..	..	..	..	..	56	42	23	14	1	....
39	"	"	...	..	..	..	..	..	58	45	23	11	4	....
0	12-13	"	...	99	99	88	76	68	61	46	26	18	5	5.68
41	"	"	...	..	..	..	..	..	60	47	25	17	7	....
42	"	"	...	..	..	..	..	..	64	50	27	16	6	....
43	"	"	...	..	..	..	..	..	55	41	20	11	1	....
44	"	"	...	..	..	..	..	..	45	33	15	9	4	....
45	12-11	"	...	99	97	84	71	63	57	44	24	15	4	5.43
46	"	"	...	..	..	..	..	..	51	49	21	9	0	....
47	10-10	Mixer............	1.5	99	95	85	76	67	61	47	26	17	3	5.59
48	10-19	"	...	99	97	88	77	68	61	45	22	14	2	5.59
49	"	"	1.0	99	98	90	80	71	64	48	26	15	3	5.79
50	12-11	Mixer (Batch 37)..	...	99	97	90	83	72	65	51	26	19	5	5.88
51	12-12	" (" 38)..	...	99	98	91	79	67	56	41	20	12	4	5.55
52	"	" (" 38)..	...	99	98	89	74	64	54	38	19	13	5	5.40
53	"	" (" 38)..	...	99	93	81	71	62	55	38	18	13	0	5.17
Average	....	....	1.7	99	96	86	75	65	57	41	23	16	3	5.46

* Sum of percentages in sieve analysis divided by 100, omitting the 1-in. sieve.

TABLE 10.—SIEVE ANALYSES AND MOISTURE CONTENT OF SAND AND PEBBLES—JOB B.

Sand and pebbles from Port Washington, Long Island.

Sample.	Date Sampled (1923).	Concrete, batch.	Moisture, per cent by weight.	Amount Coarser than each Sieve, per cent by weight.										Fineness Modulus.
				100	50	30	16	8	4	⅜	¾	1	1½	
							SAND.							
..	8-5	1	...	96	81	40	21	9	3	0	..	..	..	2.50
3	8-6	..	...	96	81	39	19	8	2	0	..	..	..	2.45
5	8-7	2	...	95	82	36	16	7	2	0	..	..	..	2.38
7	8-8	4	5.8	97	87	40	18	7	2	0	..	..	..	2.51
10	8-8	..	3.3	..	..	..	..	..	..	..	..	..	..	....
11	8-9	..	3.5	..	..	..	..	..	..	..	..	..	..	....
13	8-9	6	...	96	81	40	20	6	1	0	..	..	..	2.44
14	8-9	..	3.5	..	..	..	..	..	..	..	..	..	..	....
16	8-9	..	...	95	80	38	17	6	2	0	..	..	..	2.38
18	8-9	8	4.6	96	82	42	20	8	2	0	..	..	..	2.50
20	8-9	9	...	96	78	38	11	6	2	0	..	..	..	2.31
22	8-14	10	3.6	97	81	38	17	8	2	0	..	..	..	2.43
24	8-14	11	3.5	96	81	38	16	7	2	0	..	..	..	2.40
26	8-14	12	3.8	95	81	40	18	7	2	0	..	..	..	2.43
27	8-14	13	3.5	96	81	40	15	7	2	0	..	..	..	2.41
29	8-14	14	3.6	96	82	43	20	8	2	0	..	.	..	2.51
30	8-14	..	4.0	..	..	..	..	..	..	..	..	..	..	....
31	8-14	..	3.5	..	..	..	..	..	..	..	..	..	..	....
32	8-14	..	4.4	..	..	..	..	..	..	..	..	..	..	....
33	8-14	..	3.7	..	..	..	..	..	..	..	..	..	..	....
Average			3.9	96	82	39	17	7	2	0	..	..	..	2.43
							PEBBLES.							
2	8-6	1	...	99	99	93	97	94	82	48	16	6	0	6.33
4	8-6	..	...	99	98	97	94	93	82	51	20	9	0	6.34
6	8-7	2	...	99	97	95	93	90	96	35	8	3	0	5.93
8	8-8	4	2.0	99	97	95	93	90	75	38	13	5	0	6.00
9	8-8	5	...	99	99	98	95	94	79	45	16	5	0	6.25
12	8:9	6	...	99	97	95	92	85	72	33	7	3	0	5.30
15	8-9	7	...	100	99	98	96	91	70	35	14	7	0	6.03
19	8-9	8	...	99	99	98	96	88	72	37	18	6	0	6.07
21	8-9	9	...	100	99	97	95	88	82	39	14	6	0	6.04
23	8-14	10	2.3	100	99	99	97	93	76	52	20	9	0	6.36
25	8-14	11	...	99	99	97	96	91	73	40	13	6	0	6.08
28	8-14	13	...	99	99	98	97	93	77	45	12	4	0	6.20
30	8-14	14	1.8	99	99	98	96	89	71	34	10	4	0	5.96
Average			2.0	99	98	97	95	91	76	41	14	6	0	6.11

* Sum of percentages in Sieve Analyses divided by 100, omitting the 1-in. sieve.

TABLE 11.—UNIT WEIGHT OF AGGREGATES—JOB B.

Unless otherwise noted, the unit weights were determined by puddling dry aggregates into a ⅙ cu. ft. cylindrical measure, in accordance with the Standards of the American Society for Testing Materials. Unit weights of average samples of sand and pebbles; see Table 10 for sieve analyses.

Mixed Aggregate, per cent by weight. Sand	Mixed Aggregate, per cent by weight. Pebbles.	Unit Weight, lb. per cu. ft.
DRY AND PUDDLED.		
100 (sand only)	0	108
60	40	117
50	50	121
41	59	123
33	67	124
28	72	124
23	77	121
17	83	120
13	87	118
0	100 (pebbles only)	110
DAMP AND LOOSE.		
Sand only (4 per cent moisture)		85
Pebbles only (2 per cent moisture)		107

TABLE 12.—DATA OF CALIBRATION OF MEASURING DEVICES—JOB B.

Quantities for batch were two sacks of cement plus one shovelful, two barrows of sand and four barrows of pebbles. The mixing water used for each batch was 87 lb. plus one or more of the additional quantities listed below, usually the medium.

	Quantities. 1	2	3	4	Average.
Wheelbarrows for measuring sand:					
(a) Damp sand, lb.	148	155	164	164	159
(b) Dry sand, lb. (Weight of damp sand, less 4 per cent moisture)	142	149	157	157	151
(c) Sand, damp and loose, cu. ft.	1.75	1.83	1.94	1.94	1.87
(d) Sand, dry and puddled, cu. ft.	1.32	1.38	1.45	1.45	1.40
Wheelbarrows for measuring pebbles					
(a) Damp pebbles, lb.	228	212	210	....	217
(b) Dry pebbles, lb. (Weight of damp pebbles, less 4 per cent moisture)	223	203	206	....	212
(c) Pebbles, damp and loose, cu. ft.	2.12	1.98	1.97	....	2.02
(a) Pebbles, dry and puddled, cu. ft.	2.02	1.09	1.87	....	1.93
Water barrel					
(a) Initial quantity of water for each batch, lb.	......	......	......	......	87.0
(b) Water added to regulate consistency, lb.:					
Small amount	3.5	....	....	....	3.5
Medium amount	14.8	9.2	....	....	12.0
Large amount	35.0	....	....	....	35.0
Shovelful of cement, lb.	9.5	9.9	....	....	9.7

TABLE 13.—SIEVE ANALYSES AND MOISTURE CONTENT OF SAND AND PEBBLES—JOB C.

Sand and pebbles from Port Washington, Long Island.

Sample.	Date Sampled (1923).	Concrete, batch.	Moisture, per cent by weight.	Amount Coarser than each Sieve, per cent by weight.										Fineness Modulus.*
				100	50	30	16	8	4	⅜	¾	1	1½	
							SAND.							
3	8-21	None	...	94	74	34	17	7	1	0	..	..	..	2.27
6	8-21	None	2.2	95	80	44	21	8	1	0	..	..	..	2.49
7	8-21	None	3.3	96	81	45	21	7	1	0	..	..	..	2.51
9	8-24	1	2.5	97	78	35	17	7	1	0	..	..	..	2.37
11	8-24	2	3.8	96	77	38	18	7	1	0	..	..	..	2.38
13	8-24	3	4.7	96	79	39	19	8	1	0	..	..	..	2.45
15	8-24	4	4.5	97	77	37	19	7	1	0	..	..	..	2.38
22	8-28	5	4.2	96	78	35	15	6	1	0	..	..	..	2.31
24	8-28	6	4.5	96	78	36	16	7	1	0	..	..	..	2.34
28	8-28	8	4.7	95	80	44	24	9	1	0	..	..	..	2.53
30	8-28	9	6.2	96	80	47	24	9	2	0	..	..	..	2.58
32	8-31	10	6.0	96	82	45	22	8	2	0	..	..	..	2.55
34	8-31	11	6.0	96	80	43	22	7	1	0	..	..	..	2.49
36	8-31	12	6.2	96	79	45	26	10	3	0	..	..	..	2.59
38	8-31	13	7.3	97	80	44	22	8	2	0	..	..	..	2.53
40	9-5	14	...	98	87	41	15	6	1	0	..	..	..	2.48
42	9-5	14	...	96	80	35	14	6	1	0	..	..	..	2.32
44	9-5	15	...	95	78	41	19	6	1	0	..	..	..	2.40
4	8-21	None	...	97	82	44	23	5	2	0	..	..	..	2.53
5	8-21	None	5.1	96	82	48	23	6	0	0	..	..	..	2.55
8	8-21	None	...	96	81	44	21	7	1	0	..	..	..	2.50
..	8-21	None	...	96	80	42	33	6	2	0	..	..	..	2.49
Average			4.7	96	80	41	20	7	1	0	..	..	..	2.45
							PEBBLES.							
1	8-21	None	...	99	99	99	98	92	69	34	11	5	0	6.01
2	8-21	None	...	99	99	99	94	87	67	33	11	5	0	5.87
10	8-27	1	2.9	99	99	98	96	92	77	48	20	9	0	6.29
12	8-27	2	2.1	99	98	96	95	92	85	40	7	3	0	6.12
14	8-27	3	1.8	100	99	99	99	97	89	46	14	3	0	6.45
16	8-27	4	1.4	99	97	95	94	92	86	71	23	3	0	6.57
18	8-27	None	...	99	99	97	96	94	88	51	14	3	0	6.42
20	8-27	None	...	..	..	..	..	..	84	48	10	3	0	6.30†
21	8-27	None	...	..	..	..	..	..	81	39	9	2	0	....
23	8-27	5	2.7	99	99	98	97	95	90	47	9	1	0	6.34
25	8-27	6	3.0	99	98	96	94	91	83	40	8	2	0	6.09
27	8-27	7	3.4	99	97	95	92	89	82	39	7	1	0	6.00
29	8-23	8	2.4	99	98	97	96	95	89	46	9	2	0	6.29
31	8-23	9	3.0	99	99	98	96	95	89	53	14	4	0	5.48
33	9-7	10	...	99	98	96	93	89	77	48	23	12	0	6.23
35	9-7	11	...	99	98	96	94	88	74	41	17	7	0	6.07
37	9-7	12	4.1	99	98	95	93	89	77	46	19	8	0	6.16
39	9-7	13	...	99	99	97	96	89	76	42	16	8	0	6.14
41	9-5	14	...	99	99	98	97	95	83	53	24	12	0	6.48
43	9-5	15	...	99	99	98	96	90	68	36	17	8	0	6.05
45	9-5	..	...	99	99	98	97	93	77	45	12	4	0	6.20
Average			2.7	99	99	97	95	92	81	45	138	5	..	6.18

* Sum of percentages in sieve analyses, divided by 100, omitting the 1-in. sieve.
† Fineness modulus estimated from average analyses of particles finer than No. 4 sieve.

TABLE 14.—UNIT WEIGHT OF AGGREGATE—JOB C.

Unit weights of mixed aggregates determined in ½ cu. ft. measure in accordance with Standards of American Society for Testing Materials.
Unit weights of average samples of sand and pebbles; see Table XIII for sieve analyses.

Mixed Aggregate, per cent by weight.		Unit Weight, lb. per cu. ft.				
Sand.	Pebbles.	1	2	3	4	Average.
100 (sand only)	0	108	108	108	108	108
60	40	122	121	120	120	121
50	50	124	124	123	124	124
40	60	127	126	127	126	126
35	65	128	127	127	128	128
33	67	129	128	126	128	128
30	70	128	128	125	127	127
25	75	126	125	123	125	125
20	80	124	122	121	122	122
0	100 (pebbles only)	111	112	110	111	111

TABLE 15.—SIEVE ANALYSIS OF AGGREGATES—JOB D.

Aggregate: "Ready-mix" gravel from Port Jefferson, Long Island.

Sample.	Date Sampled (1923).	Place Samdled.	Amount Coarser than each Sieve, per cent by weight.										Fineness Modulus.*
			100	50	30	16	8	4	⅜	¾	1	1½	
1	9-17	Stock pile	100	99	93	82	73	65	51	34	..	11	6.08
2			100	99	89	81	72	63	48	26	..	5	5.84
3			100	99	92	76	66	58	39	19	..	4	5.53
4			99	98	90	67	55	44	31	19	..	4	5.07
4			100	99	94	82	59	46	32	16	..	1	5.29
5			99	90	89	71	57	46	31	12	..	2	5.06
6			99	98	89	77	56	52	38	19	..	4	5.32
7	10-1	Mixer (Batch 3)	100	99	89	75	66	58	46	25	16	5	5.63
8	10-2	" (" 4)	100	99	91	77	65	54	39	20	12	2	5.47
9	10-2	" (" 5)	99	98	87	70	59	51	38	20	12	2	5.24
10	10-2	" (" 6)	99	98	88	73	64	56	41	22	13	1	5.42
11	10-4	" (" 7)	99	98	87	71	62	55	41	20	..	3	5.36
12	10-4	" (" 8)	99	97	85	71	63	57	45	26	..	5	5.48
Average			99	99	90	75	63	54	40	21	13	3	5.45

* Sum of percentages in sieve analysis, divided by 100, omitting the 1-in. sieve.

TABLE 16.—SIEVE ANALYSIS OF AGGREGATE—JOB E.

Aggregate: "Ready-mix" gravel from Marlborough-on-the-Hudson.

Sample.	Date Sampled (1923).	Scow Sampled.	Amount Coarser than each Sieve, per cent by weight.										Fineness Modulus.*
			100	50	30	16	8	4	⅜	¾	1	1½	
1	9-14	Bishop, 18 ft. from stern.....	98	97	93	87	79	72	49	14	3	0	5.89
2	" "	" 20 " " "	98	91	79	64	49	40	29	12	3	0	4.62
3	" "	" 6 " " top, 25 ft. from stern................	99	96	91	82	72	63	51	22	5	0	5.76
4	" "	Bishop, near center, 18 in. down	98	94	84	69	55	47	39	18	6	0	5.04
5	" "	" bow, 18 in. down......	99	94	87	76	66	59	41	11	3	0	5.33
6	9-17	Marlboro, No. 10............	99	96	89	79	67	54	29	6	1	0	5.19
7	" "	" " "............	99	98	94	88	79	70	43	10	4	0	5.81
8	" "	" " "............	98	95	88	78	67	60	41	10	3	0	5.37
9	" "	" " "............	98	95	88	77	64	52	37	16	4	0	5.27
10	" "	" " "............	98	94	84	68	49	35	24	9	3	0	4.61
11	9-18	Wm. Howland...............	98	90	80	69	57	53	40	16	7	0	5.03
12	" "	" "	98	94	85	72	58	47	38	15	5	0	5.07
13	9-23	Eads.......................	98	94	85	73	63	55	44	20	7	0	5.32
14	" "	"	99	95	89	80	70	62	40	14	4	0	5.49
15	" "	"	98	96	88	81	72	65	43	11	2	0	5.54
16	9-25	D. W. Mack.................	99	98	94	87	80	72	51	12	3	0	5.93
17	" "	" " "	98	93	82	70	55	46	36	17	6	0	4.97
18	" "	" " "	99	94	85	73	59	50	37	14	5	0	5.11
Average...............................			99	95	87	76	65	56	40	14	4	0	5.30

* Sum of percentages in sieve analysis, divided by 100, omitting the 1-in. sieve.

TABLE 17.—MISCELLANEOUS LABORATORY TESTS OF CEMENT.

Tests made in accordance with Standard Specifications and Tests for Portland Cement of the American Society for Testing Materials.
Each value is the average of two tests made on different days.

Cement Lot.	Brand of Cement.	Job.	Date (1923).			Residue on 200 Mesh Sieve.	Normal Consistency.	Time of Setting.				Soundness Test over Boiling Water.
								Vicat Needle.		Gillmore Needle.		
			Sampled.	Received.	Tested.			Initial, h. m.	Final, h. m.	Initial, h. m.	Final, h. m.	
7049–51	Penna...	A	9-14, 19, 20	10-2	10-26	16.6	22.7	3 35	8 25	5 40	9 20	O.K.
7145	Penna...	A	11-16	11-26	12-20	16.4	24.5	3 20	9 45	5 30	11 05	O.K.
6966	Penna...	B	7-7, 9, 14	7-18	10-26	19.4	23.5	3 25	8 00	5 45	9 10	O.K.
6986	Whitehall	C	7-24, 28, 31	9-10	10-26	19.8	23.0	3 25	7 50	5 40	8 40	O.K.
7098	Alpha...	D	10-31, 11-1	11-2	12-20	18.8	23.0	3 50	7 50	6 30	9 00	O.K.
7044	Atlas....	E	9-20	9-29	10-26	19.0	32.5	3 20	8 20	5 40	9 20	O.K.

TABLE 18.—CONCRETE AND MORTAR TESTS OF CEMENT IN LABORATORY.

Strength tests of 1-3 standard sand mortar briquets, and 2 x 4 in.-cylinders.
Compression tests of 6 x 12-in. concrete cylinders.
Aggregate for concrete: sand and pebbles from Elgin, Ill., graded 0-1½ in. (m=5.51).
Relative consistency of concrete, 1.00.
Cement assumed to weigh 94 lb. per cu. ft.
In comparing strength values of concrete in this table with values obtained from the field tests it should be borne in mind that the laboratory cylinders were of drier consistency than those made in the field and therefore would be expected to give higher strengths at all ages.

Each value is the average of five tests unless otherwise noted.

Cement Lot.	Tensile Strength, lb. per sq. in.			Compressive Strength, lb. per sq. in.					
	1:3 Standard Sand Briquets.			1:3 Standard Sand. 2 x 4-in. Cylinders.			1:5 Concrete. 6 x 12-in. Cylinders.		
	7 days.	28 days.	3 mo.	7 days.	28 days.	3 ms.	7 days.	28 days.	3 mo.
7049-51	360	420	415	2080	3370	4110	2300	3640	4640
7145	365*	440*	535	2580*	3440*	4200	....	....	....
6966	280	395	440	1550	2020	2960	1720	2680	3370
6986	360	430	450	1820	3090	3700	2140	3500	4230
7098	295	395	470	1760	2700	3360	1570*	2680	4120
7044	325	370	445	2050	3200	3800	....	....	....

* Average of four tests.